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A SURVEY OF OPERATIONS RESEARCH TECHNIQUE
USAGE IN THE U.S. MARINE CORPS

Michael C. Mitchell

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

A SURVEY OF OPERATIONS RESEARCH TECHNIQUE
USAGE IN THE U.S. MARINE CORPS

by

Michael C. Mitchell

March 1981

Thesis Advisor:

G. Thomas

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A Survey of Operations Research Technique Usage in the U.S. Marine Corps		5. TYPE OF REPORT & PERIOD COVERED Master's thesis; March 1981
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Michael C. Mitchell		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE March 1981
		13. NUMBER OF PAGES 104
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Operations Research Technique Usage Operations Analyst (MOS code 9650) U.S. Marine Corps		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This thesis presents the results of a mailed survey of all officers currently serving on active duty in the United States Marine Corps who possess a secondary Military Occupational Specialty (MOS) of Operations Analyst (MOS code 9650). The questionnaire used was designed to determine the usage frequency and the relative importance of each of 35 Operations Research (OR) techniques and application areas		

(20. ABSTRACT Continued)

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A Survey of Operations Research Technique
Usage in the U.S. Marine Corps

by

Michael C. Mitchell
Captain, United States Marine Corps
B.S., United States Naval Academy, 1973

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
March 1981

ABSTRACT

This thesis presents the results of a mailed survey of all officers currently serving on active duty in the United States Marine Corps who possess a secondary Military Occupational Specialty (MOS) of Operations Analyst (MOS code 9650). The questionnaire used was designed to determine the usage frequency and the relative importance of each of 35 Operations Research (OR) techniques and application areas to these Marine officers during their most recent tours in 9650 billets. In addition, the results were classified according to individual service rank, function area and type of OR work performed and a series of nonparametric statistical tests was conducted to determine significant differences. Comments elicited by the survey were also analyzed and recommendations were made based upon the conclusions drawn.

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I. BACKGROUND

A. INTRODUCTION

This thesis presents the results of a mailed survey of all officers currently serving on active duty in the United States Marine Corps who possess a secondary Military Occupational Specialty (MOS) of Operations Analyst (MOS code 9650). The questionnaire used was designed to determine the usage frequency and the relative importance of each of 35 Operations Research (OR) techniques and application areas to these Marine officers during their most recent tours in 9650 billets. In addition, the results were classified according to individual service rank, function area and type of OR work performed and a series of statistical tests was conducted to determine significant differences. Comments elicited by the survey were also analyzed and recommendations were made based upon the conclusions drawn.

B. HISTORY OF OPERATIONS ANALYSIS IN THE MARINE CORPS

The Marine Corps initiated an "in-house" operations analysis capability in 1957, when a civil service billet was established at Marine Corps Headquarters (HQMC) in Washington, D.C. [Ref. 1]. Subsequently, the Commandant of the Marine Corps decided that there existed a need for Marines educated at the graduate level in the field of Operations Research/ Systems Analysis (OR/SA) so, in 1958, the first Marine officer

was assigned to the Naval Postgraduate School (NPS) to study their Operations Research curriculum. During the next few years only about four or five Operations Analyst billets were identified by the Marine Corps, consequently, the input of Marines to the NPS program was small, averaging only about two per annum through 1963. Although limited operations analysis support was available to the Marine Corps through the Navy's CNO Operations Evaluation Group, the Marines did not possess a significant analysis capability until 1965, when the Marine Corps Operations Analysis Group was established as a separate division at the Center for Naval Analysis, a private, non-profit organization under contract to the Navy and administered by the University of Rochester. That same year, the first Fleet Marine Force (FMF) operations analysis section was formed at FMF Pacific.

During the middle sixties the requirements for Marine Operations Analysts accelerated rapidly due to an increased recognition of the value of analytical problem solving. Correspondingly, the annual personnel input to the OR/SA curriculum at postgraduate school increased until the current level of about 10 officers per year was reached. Although the great majority of these officers attend the Naval Postgraduate School at Monterey, California, a few also attend civilian universities. Presently, there are 19 Marine officers enrolled in the OR/SA curriculum at the Naval Postgraduate School and 2 enrolled at civilian schools.

These personnel, once educated, will be assigned the Military Occupational Specialty code 9650 and given the title Operations Analyst. The Marine Corps MOS Manual describes the duties and tasks which these people should be capable of completing as follows:

Duties and Tasks: Participates in the following: construction of models, manual or computer, for analysis or comparison of military activities, operations, weapons systems, and force structures; the gathering of empirical data used in support of analysis, comparison, or war gaming of military activities, weapons systems and plans; cost effectiveness studies to analyze weapons systems, operational concepts, and resource allocation. Conducts statistical evaluations and comparisons of the results of such tests and writes technical reports on results. Directs, supervises, conducts, or participates in war gaming or simulation activities, including preparation of rules or flow charts, conduct of game or simulation, assessment of the game moves, of simulation steps, evaluation of the results, and determination of appropriate measures of effectiveness. Performs technical liaison between military organizations and activities engaged in analytical or evaluation work and technical assistance [for] contractors supporting the military activity. Performs any or all of the above duties and tasks at research and development activities, management activities, or with operational units of the Fleet Marine Force. [Ref. 2]

In less sophisticated terms, a Marine Operations Analyst is an individual capable of performing operations analysis, where such analysis, as defined by the Marine Corps, is "the application of scientific methods to perform analysis directed toward improving the operational effectiveness of organizations and the operating efficiency of organized man-machine systems in achieving their objectives" [Ref. 3:p. 1]. While the term "operations analysis" and "operations research" are synonymous, the term "systems analysis" carries a slightly different

connotation, being "the application of scientific methods to assist a decision maker to choose among alternatives by a systematic investigation of the relevant costs, risk and meaningful effectiveness of alternative systems, equipments or organizations" [Ref. 3:p. 2].

Operations analysis is used to address technical, tactical problems while systems analysis often addresses the more loosely defined strategic problems. The essence of an Operations Analyst's work is to provide a decision maker with an analytical method for choosing among alternative procedures, allocations and/or courses of action.

We can gain a better idea of operations analysis in the Marine Corps by reviewing how analysts are trained.

C. MARINE CORPS SPECIAL EDUCATION

To support the educational requirement for trained Operations Analysts, the Marine Corps has two advanced education programs: the Special Education Program (SEP) [Ref. 4] and the Advanced Degree Program (ADP) [Ref. 5].

The Special Education Program allows voluntary selectees to attend either the Naval Postgraduate School or one of a limited number of specified civilian universities in order to study for an advanced degree in a number of selected fields, including OR/SA. The Marine Corps pays all tuition and required academic fees as well as providing normal pay and allowances while the officer is attending school.

The Advanced Degree Program was established to augment the SEP by providing an additional means for career officers

to obtain a graduate education in order to qualify for SEP billets. Through this program, officers may voluntarily apply to civilian universities acceptable to the Marine Corps to study in a field in which the Corps has realized a personnel shortage. During the course of attendance, each officer continues to receive his or her normal pay and allowances from the Marine Corps but must bear the cost of tuition and textbooks.

Officers applying for either program must agree not to submit a resignation nor to request separation while participating in the program and must further agree to remain on active duty, after completion of their education or upon separation from the program, for a period of 3 to 4 years (depending upon the length of their course of instruction). Upon successful completion of one of these programs, the officers are assigned a secondary MOS and are sent to SEP billets requiring the use of their newly acquired skills. (The only exceptions to this immediate SEP assignment policy are officers who are scheduled for an overseas assignment or officers who have studied in a field in which no billets are currently available). In any event, an officer with a SEP MOS can expect to be required to serve alternating tours in SEP billets thereafter.

D. SPECIAL EDUCATION PROGRAM BILLETS

The Marine Corps currently (1980) has 414 billets designated as Special Education Program (SEP) billets, the number of billets authorized at any time being the result of an

iterative justification process. Recommendations for establishment of SEP billets can be made to the Deputy Chief of Staff for Manpower by

- 1) Marine Corps field commanders (Divisions, Wings, etc.)
- 2) SEP discipline sponsors
- 3) Table of Organization (T/O) sponsors

SEP discipline sponsors are the HQMC staff sections designated as the "in-house" expert on their particular discipline. (The SEP discipline sponsor for OR/SA is the Deputy Chief of Staff for Research, Development and Studies.) The T/O sponsor is the HQMC staff section with administrative responsibility for the Table of Organization which includes the recommended billet.

Specific requirements and justification for the establishment of a new billet must be submitted in the form of a completed Billet Education Evaluation Certificate. In order for a billet to be identified as requiring graduate level education, it must be determined that such a level is either "Necessary" or "Desirable" for the proper functioning of the billet incumbent. The classification of "Necessary" is assigned only to billets meeting one of the following criteria: [Ref. 6: p. 2]

- 1) Billets which are required by law or DOD policy to be filled by individuals possessing graduate level education in a specific field of study.
- 2) Billets in which the primary duties of the incumbent cannot be satisfactorily performed except by

individuals possessing qualifications which can be acquired only through graduate education in a relevant field of study.

- 3) Billets which must be filled by individuals who are required to exert direct technical supervision over military or civilian billets with graduate education prerequisites.

The classification of "Desirable" is assigned to billets not meeting any of the above criteria, but which can be most effectively filled by individuals who have had graduate training.

In the billet approval process the discipline sponsor has the major responsibility for determining if recommended billets actually require graduate education. In addition, the sponsor is required to conduct an annual review of all current billet educational requirements to ensure that each educational level is continually warranted.

There are, presently, 53 SEP billets specified as being Operations Analyst billets. (The number of Marine Operations Analysts currently on active duty is 77, well below the 127 necessary in order to meet the Marine Corps desired level of 2.4 trained officers for each billet.) The Marine Corps Operations Analysis Group located at the Center for Naval Analysis currently represents the largest single OR/SA capability in the Marine Corps. This organization, comprised of civilian and Marine Operations Analysts and support personnel, provides a detachment of analysts to the Marine Corps Development and Education Center (MCDEC) and one analyst to

each of the FMF Headquarters. Additionally, smaller operations analysis sections consisting of military and/or civil service Operations Analysts have been established as well as certain individual billets. The majority of these sections and billets are currently located at HQMC and MCDEC although there are also individuals located with joint commands such as the Department of Defense, the Joint Chiefs of Staff and the Defense Communications Agency.

The majority of Operations Analyst billets being spread throughout the Marine Corps rather than being pooled at a single location reflects the current Marine Corps policy that Operations Analysts should provide direct support to individual commanders and staff section heads. In fact, "to employ analysts in a substructure below this level tends to reduce their effectiveness" [Ref. 3:p. 5].

E. PROBLEM STATEMENT

Upon completion of interviews with several persons presently assigned to MOS 9650 SEP billets, the author concluded that the official Marine Corps explanation of the tasks and duties assigned to these personnel does not always reflect the actual functions of their billets. In addition, discussions with students enrolled in the OR/SA curriculum at NPS revealed an unclear perception of the real responsibilities and functions of Marine Operations Analysts "in the field". This results from the lack of a published, clear definition of the actual roles played by Marine Operations Analysts and an

explanation of the techniques that they employ. What tasks are Marine Operations Analysts actually being required to complete? Are they being taught the techniques that they will be obliged to understand in order to complete their tasks? A method of answering these questions is to ask the officers currently assigned the 9650 secondary MOS what tasks they have been required to complete and what techniques they used. The answers from such a survey can then be utilized in the evaluation and possible modification of the curriculum employed in educating potential Marine Operations Analysts at the Naval Postgraduate School. Additionally, a survey of OR/SA techniques currently in use by Marine analysts may provide a basis for developing a program of elective courses that might be recommended to future Marine Corps students at NPS.

The purpose of this thesis was to conduct a survey of the Operations Research techniques currently being used by Marine 9650's and, through statistical inference and comparative analysis, make recommendations for improving the training and utilization of Marine Operations Analysts.

F. PREVIOUS STUDIES

Studies of OR technique usage during the last ten years include surveys of both corporate and military usage. In 1977, Ledbetter and Cox surveyed the 500 largest U.S. industrial firms as listed by Fortune magazine in 1975 [Ref. 7]. Analyzing their 176 returns with respect to the use of OR techniques and the specific areas of OR application, they

found that a great majority of the responding firms used regression analysis to at least some degree, while a nearly like number used simulation (in production) and linear programming (see Table I). Simulation and linear programming reflected the greatest breadth of usage over a wide range of application areas while regression analysis showed the highest ranking for across-the-board degree of usage within the firms.

TABLE I

CORPORATE OR TECHNIQUE USAGE (LEDBETTER AND COX)

<u>Technique</u>	<u>% of Firms Reporting Usage</u>
Regression Analysis	90.5
Simulation	88.6
Linear Programming	84.6
Queueing Theory	63.4
Network Models	60.9
Dynamic Programming	46.4
Game Theory	40.3

In their study of 137 Case Western Reserve University alumni, Rasmussen and George asked the respondents to report the value to them during their careers of various theoretical and methodological subject areas related to the Operations Research field [Ref. 8]. The following order of value was reported by respondents possessing a Master of Science degree:

Statistical Methods
Systems Analysis
Forecasting
Information Systems
Simulation
Decision Theory
Linear Programming
Scheduling Theory
Production Management
Inventory Theory
Stochastic Processes
Non-linear Programming
Integer Programming
Dynamic Programming
Queueing Theory

Other techniques and related subject areas considered to be important by those answering the survey included: Networks, Graphs, Reliability Theory, Modeling, Case Studies, Problem Formulation, Computing, Cost/Benefit Analysis, Structure of Organizations, Philosophy of Management, Communications and "the organization survival of the Operations Research practitioner". Also reflected in this study were the inferences that Ph.D. respondents felt that the Mathematical Programming areas were more useful than the M.S. respondents did and that Ph.D. respondents reported a higher level of receptivity to OR techniques by their employers than did the M.S. respondents.

In research conducted in 1977, Thomas and DaCosta [Ref. 9] compared their survey of 150 California firms and institutions and "Fortune 500" corporations with surveys that had been conducted by Hovey and Wagner [Ref. 10] in 1958, Schumacher and Smith [Ref. 11] in 1964, and Turban [Ref. 12] in 1969. Their findings on usage of OR techniques, as shown in Table II, were similar to those of Ledbetter and Cox. In addition, they found that, when the users were queried as to the types of

TABLE II

CORPORATE OR TECHNIQUE USAGE (THOMAS AND DACOSTA)

<u>Technique</u>	<u>% of Firms Reporting Usage</u>
Statistical Analysis	93
Simulation	84
Linear Programming	79
PERT/CPM	70
Inventory Theory	57
Queueing Theory	45
Non-linear Programming	36
Heuristic Programming	34
Bayesian Decision Analysis	32
Dynamic Programming	27
Risk Analysis	3
Integer and Mixed Programming	2
Delphi	1
Financial Methods	1

difficulties that are encountered in attempting to implement OR work, the most frequently mentioned difficulties were user commitment, user understanding and organizational resistance to change. Specifically, they felt that "if the manager who must use the proffered solution does not understand its basis there will be friction and difficulties" [Ref. 9:p. 108].

All of the above-noted studies were related to private industry which has more easily-measured overall objectives such as profit and profit contribution. This might well cause

corporate survey results to be far different from those that would be obtained from an inquiry into the usage of OR techniques by military personnel.

In 1978, Obert conducted a telephone survey of ninety percent (328) of the Operations Research and Systems Analysis positions within the Army [Ref. 13]. His figures for frequency of OR technique usage for individuals characterized as holding OR/SA engineer billets are shown in Table III. One should bear in mind that the principal difference between this survey and most of the ones previously mentioned is that in this survey individuals were asked to report frequency of usage of OR techniques while, in the corporate surveys, organizations were asked to report usage frequencies. Obert found that almost ninety percent of his respondents characterized their duties as either doing original OR/SA research, correlating the work of other researchers or reviewing OR/SA work. Additionally, he found that while over eighty percent of his respondents worked with established computer programs, the majority did not do their own computer programming (FORTRAN being the programming language most frequently employed by the program-writing minority). Finally, it was determined that, while the overall results for OR/SA engineers showed that almost three-fourths of the respondents said that they spent one-half or less of their time using quantitative analysis or OR/SA techniques compared to their other daily duties, Captains and Majors, apparently, spent more of their time doing analysis than did Lieutenant Colonels and Colonels.

TABLE III

OR TECHNIQUE USAGE BY ARMY OR/SA ENGINEERS

<u>Technique</u>	<u>% of Individuals Reporting Usage</u>
Parametric Statistics	98.5
Probability	96.5
Formal Data Analysis	93.9
Measures of Effectiveness	78.8
Simulation Models and Applications	73.8
Networks, Flows and Graphs	65.6
Combat Models	64.6
Decision and Risk Analysis	64.2
War Games	63.1
Experimental Design	54.1
Nonparametric Statistics	48.5
Human Factors	45.4
Stochastic Models	44.9
Learning Curves	44.5
Cost Estimating	41.9
Linear Algebra	41.4
Linear Programming	37.9
Calculus	32.8
Economics and Economic Analysis	25.7
Manpower Models	24.6
Accounting and Financial Applications	23.2
Dynamic and Non-linear Programming	21.7
Cost Estimating Relationships	19.2
Economic Input-Output Models	8.1

The following chapters explain the planning, conduct and results of the work undertaken by the author in an attempt to ascertain the frequency of usage of OR techniques in the Marine Corps. Chapter II describes the experimental methodology developed to obtain measurable results from a survey of Marine Operations Analysts. These results are presented and analyzed in Chapter III. Numerical data obtained from the questionnaires are categorized into several groups and the statistical tests that were conducted are described. Comments made by the respondents are grouped according to theme and subjectively discussed. Finally, in Chapter V, conclusions are drawn from the results of the analysis and recommendations for the improved utilization of 9650's are made.

II. METHODOLOGY AND CONDUCT OF THE EXPERIMENT

Since the experiment population was well defined (all Marine personnel holding a MOS of 9650 and currently on active duty) and equally easy to locate, it was decided that a mailed questionnaire, as opposed to a telephone survey, would be the most appropriate method of conducting the survey. This would provide a controlled, unbiased means of obtaining answers while allowing individuals the time necessary to think about each question before responding. Since a mailed questionnaire might result in a lower response rate than could be obtained via personal contact, it was decided that, upon reaching a return rate of 75%, the remaining individuals who had not responded would be contacted by telephone to determine if they required additional information or assistance. A final response rate goal of 90% was deemed to be reasonable since it was felt that at least 10% of the population might not be able to be reached due to being deployed overseas, enroute to a new duty station, on leave, etc.

The questionnaire was designed so that each question would obtain replies which could be summarized in a fashion capable of answering questions implied by the thesis objectives (see Appendix A for questionnaire format). The first four questions were directly related to the respondents' billets, requesting the billet title, location and general function area as well as the service rank of the individual and the type of OR work

that the billet required him to do the most. The answers obtained from these questions would be used to group the returns for detailed study during their analysis. Questions 5 and 6 were related to computer programming and the use of preprogrammed computer packages, inquiring as to the types of computer languages used, if any, and the reasons for their usage. In an attempt to secure some measure of the usage frequency and importance of OR techniques to the practicing analysts, questions 7 and 8 were developed, allowing the respondents to rate each subject according to their personal experiences. Question 9 was added as an attempt to include in the analysis any subject (not included in questions 7 and 8) that the respondents used frequently or felt to be important to them. Question 10 was an attempt to ascertain how much of their work time analysts are spending on OR labors. Question 11 would help to determine the acceptance level of OR work "in the real world", while responses obtained from question 12 would result in subjective recommendations for the better utilization of Marine Operations Analysts.

Recognizing that the answers obtained would be clearly of a subjective nature and that the form of the underlying distribution of the answers would be unknown, it was decided that nonparametric (i.e., distribution-free) methods of statistical analysis would be appropriate for analyzing the returns. Parametric methods require that more assumptions be made than do nonparametric methods, consequently nonparametric statistical

tests are generally less powerful than parametric statistical tests.

This power-deficiency can be corrected when using non-parametric methods, however, by drawing a larger sample size from the population [Ref. 14:p. 21] (hence, the imperative of the return rate goal of 90%). One assumption that must be made, though, whether using parametric or nonparametric methods is that the observations are independent. Additionally, nonparametric methods as used in this study require that all questions intended to be analyzed be designed so that answers are at least based on an ordinal scale and that all observations are drawn from an underlying continuous distribution.

The strategy for the data analysis was first to determine the overall frequency of usage and perceived importance of a number of OR techniques and application areas and then to determine if there were differences according to frequency of usage or perceived importance. One might expect that there would be differences and this, in fact, was borne out by the results. A more difficult question to answer, however, is what are the possible causes of the differences. The data were grouped according to the service rank of the individuals, the functional area related to their billets and the type of OR work that their billets required them to do the most and statistical tests were conducted to determine possible causes for differences and relationships between the groups. These tests, the conclusions drawn from them and various recommendations are presented in the chapters that follow.

III. DATA ANALYSIS

A copy of the survey questionnaire contained in Appendix A was sent to each of the 77 Marine officers designated as Operations Analysts (Military Occupational Specialty 9650) who are currently on active duty. Individuals were asked to base all of their answers on the most recent MOS 9650 billet in which they had served. Those who had never served in a MOS 9650 billet were asked to state so and return the unanswered questionnaire. A total of 72 persons returned their questionnaires for a return rate of 93.5%. Six of these people stated that they had never held a 9650 billet, leaving a usable sample of 66 respondents for analysis (i.e., a 83.3% usable return rate).

A. RANK

Table IV contains frequency-of-answer data relating individual service rank. The reader is reminded that the tabulations do not reflect the current status of the population, but,

TABLE IV

SERVICE RANK DURING MOST RECENT 9650 BILLET

<u>Rank</u>	<u>Raw Score</u>	(Percentage)
Captain	17	(25.8)
Major	35	(53.0)
Lieutenant Colonel	12	(18.2)
Colonel	<u>2</u>	(3.0)
Total	66	(100.0)

rather, the status of each individual during his most recent tour in a 9650 billet. As an illustration: 40 of the 77 officers sent questionnaires currently hold the rank of Lieutenant Colonel but only 12 officers of the 66 respondents reported that they held that rank during their most recent 9650 billet assignment. As can be seen, a majority of the respondents said that they had held their billets as Majors.

B. FUNCTION AREA

Respondents were fairly evenly spread among functional areas of employment (see Table V). Eight individuals reported that their assignments were related to a combination of the listed function areas while an equal number said that their jobs were associated with a different field of work than those

TABLE V
FUNCTIONAL AREA

<u>Functional Area</u>	<u>Raw Score</u>	(Percentage)
Manpower	11	(16.7)
Logistics	8	(12.1)
Finance	1	(1.5)
Operations and Plans	7	(10.6)
Test and Evaluation	14	(21.2)
Aviation	6	(9.1)
Instruction	3	(4.5)
Combination	8	(12.1)
Other	<u>8</u>	<u>(12.1)</u>
Total	66	(100.0)

listed (e.g., system development, research and development [5], studies and long-range planning).

C. TYPE OF OR WORK DONE

As Table VI indicates, one-third specified that they did original OR work most of the time. A nearly like number (34.8%) reported that most of their OR work was done reviewing work completed outside of their sections. Two questions of interest: Does the most frequent type of OR work done vary by rank and does the most frequent type of OR work done vary by function area?

TABLE VI

TYPE OF OR WORK DONE

<u>Type of Work</u>	<u>Raw Score</u>	(Percentage)
Original	22	(33.3)
Correlate	4	(6.1)
Review	23	(34.8)
Instructor	3	(4.5)
Combination	6	(9.1)
Other	3	(4.5)
None	<u>5</u>	<u>(7.6)</u>
Total	66	(100.0)

D. TYPE OF WORK DONE BY RANK OF OFFICER

To answer the first question, the null hypothesis that there is no difference in the frequency distribution of type of OR work done between the more junior ranks of Captain and

Major and the more senior ranks of Lieutenant Colonel and Colonel was tested. The associated frequency distributions are shown in Table VII. A Chi-square (χ^2) test indicates that there is not a significant difference between

TABLE VII
SERVICE RANK VERSUS TYPE OF OR WORK DONE

	Captains/ Majors	Lieutenant Colonels/ Colonels	Total
Original	20	2	22
Correlate	4	0	4
Review	15	8	23
Instructor	2	1	3
Combination	6	0	6
Other	1	2	3
None	<u>4</u>	<u>1</u>	<u>5</u>
Total	52	14	66

$$\chi^2(6) = 11.138$$

$$P \text{ Value} = 0.084$$

junior and senior officers based upon the type of OR work performed ($P = 0.084$). (The P value is the smallest value of type I error probability for which there would be a rejection of the null hypothesis. It was decided by the author that a critical level of 0.05 would be utilized for the rejection of any null hypothesis in this study).

It should be noted that, in only two of the categories listed, the expected frequencies are greater than five. Some

authors feel that when the degrees of freedom of a χ^2 test are greater than one the χ^2 test should be used only if fewer than twenty percent of the category cells have an expected frequency of less than five and if none has an expected frequency of less than one [Ref. 14:p. 110]. However, Lancaster notes that

it used to be feared by authors that the test would not be accurate if carried out when any class expectation was less than 10. These fears have proved unjustified by the investigations of authors using simulation methods or complete enumeration of all possibilities in given discrete distributions. [Ref. 15:p. 175]

While Lancaster does go on to concede that it is "probably desirable" to have all expectations greater than one, he does not commit himself to making any concrete ruling on the matter.

As a check on the above test, a χ^2 test was also conducted with a collapsed contingency table comprised of row categories: "Original", "Review" and "Other". A P value of 0.105 was obtained, reinforcing the initial failure to reject the null hypothesis.

E. TYPE OF WORK DONE BY FUNCTIONAL AREA

In addressing the question of the relationship of the type of most frequent OR work done and function area, a χ^2 test of independence was again used. However, when a contingency table was set up utilizing all of the categories in questions 3 and 4 of the questionnaire, it was found that 63% of the cell expected frequencies were less than one. Since this seemed to be stretching the rule-of-thumb for cell minimum expected

frequencies a bit too far, the categories were collapsed to those shown in Table VIII. The hypothesis that there is no difference between individuals employed in each of the listed function areas based upon the type of OR work their billets require them to do the most was rejected ($P = 0.0005$).

TABLE VIII
FUNCTIONAL AREA VERSUS TYPE OF OR WORK DONE

	Manpower	Logistics	Operations and Plans	Test and Evaluation	Aviation	Combination	Other	Total
Original	4	2	1	5	3	7	0	22
Review	4	4	3	6	3	0	3	23
Correlate, Instructor, Combination, Other	2	0	2	3	0	1	8	16
Total	<u>10</u>	<u>6</u>	<u>6</u>	<u>14</u>	<u>6</u>	<u>8</u>	<u>11</u>	<u>61</u>

$$\chi^2(12) = 34.92$$

$$P \text{ Value} = .0005$$

F. COMPUTER PROGRAMMING

Only 39.4% of the respondents reported that their billet assignments required them to do their own computer programming. It was interesting to note that, while 44.2% of those who had been Captains or Majors during their most recent 9650 tour reported being required to do their own programming, only 21.4%

of those who had been Lieutenant Colonels or Colonels reported such. Table IX lists the reported frequency of programming language use. Fortran is by far the language most commonly used by the surveyed analysts, familiarity and availability being the most often reported reasons for its usage. In regard to all of the other listed languages, availability and scientific suitability of the language were the most often reported reasons for usage.

TABLE IX

TYPE OF COMPUTER PROGRAMMING LANGUAGE USED

<u>Language</u>	<u>Frequency of Answer</u>	<u>(Percentage)</u>
Fortran	19	(38.8)
Basic	9	(18.4)
Mark IV	6	(12.2)
APL	5	(10.2)
GPSS	3	(6.1)
SPSS	3	(6.1)
Cobol	3	(6.1)
NIPS	<u>1</u>	<u>(2.0)</u>
Total	49	(100.0)

A clear majority (66.7%) of the respondents reported interacting with established computer programs but, this time, a higher percentage of Lieutenant Colonels and Colonels (71.4%) reported using established programs than did Captains and Majors (65.4%).

G. FREQUENCY OF USE OF OR TECHNIQUES

In question 7 the respondents were asked to indicate the frequency of usage of each of 35 OR techniques and application areas by specifying "Never", "Sometimes" or "Always". Appendix B is comprised of frequency tables for the answers obtained while cumulative frequencies for each subject are presented in bar graphs in Figure 1. Each of the surveyed techniques and application areas is listed on the horizontal axes of the graphs while the vertical axes represent the percentage of individuals responding. The cross-hatched section of each column indicates the percentage of personnel reporting that they use the techniques "Always" while the clear enclosed section reflects the percentage reporting that they use them "Sometimes". As an example, in Figure 1 the graph shows that 21% of the 66 respondents stated that they used Probability Theory "Always" and 56% said that they used it "Sometimes". Thus, a total of 77% of the sample reported using Probability Theory at least sometimes while the remaining 23% of the graph is left blank, representing those who responded that they never use that particular subject.

Parametric Data Analysis and Statistical Inference, Cost Effectiveness, Networks and Probability Theory received the greatest number of responses for "Sometimes" and "Always" while, surprisingly, all of the mathematical programming techniques, including Linear Programming, received few usage responses.

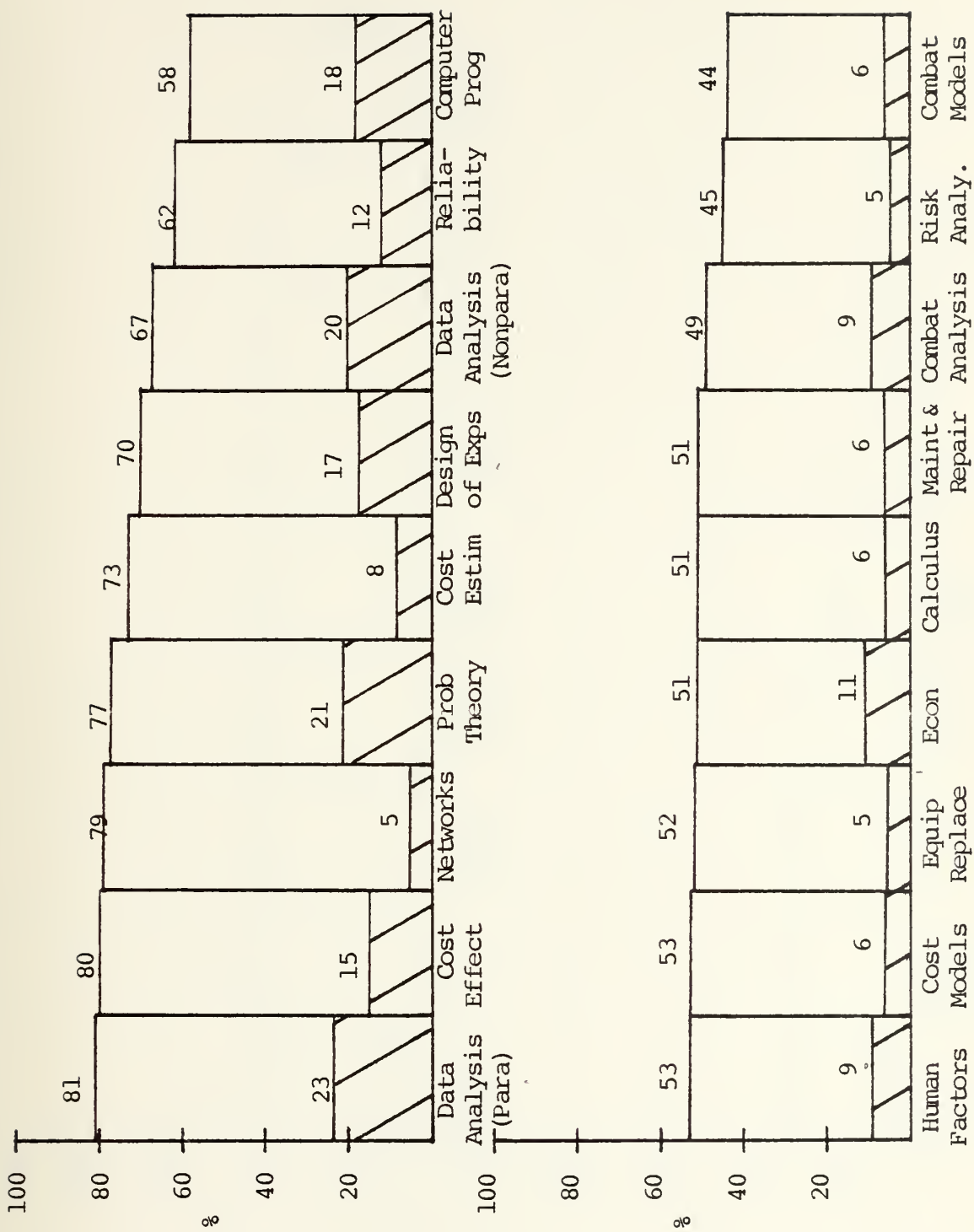


Figure 1. FREQUENCY OF USE OF OR TECHNIQUES

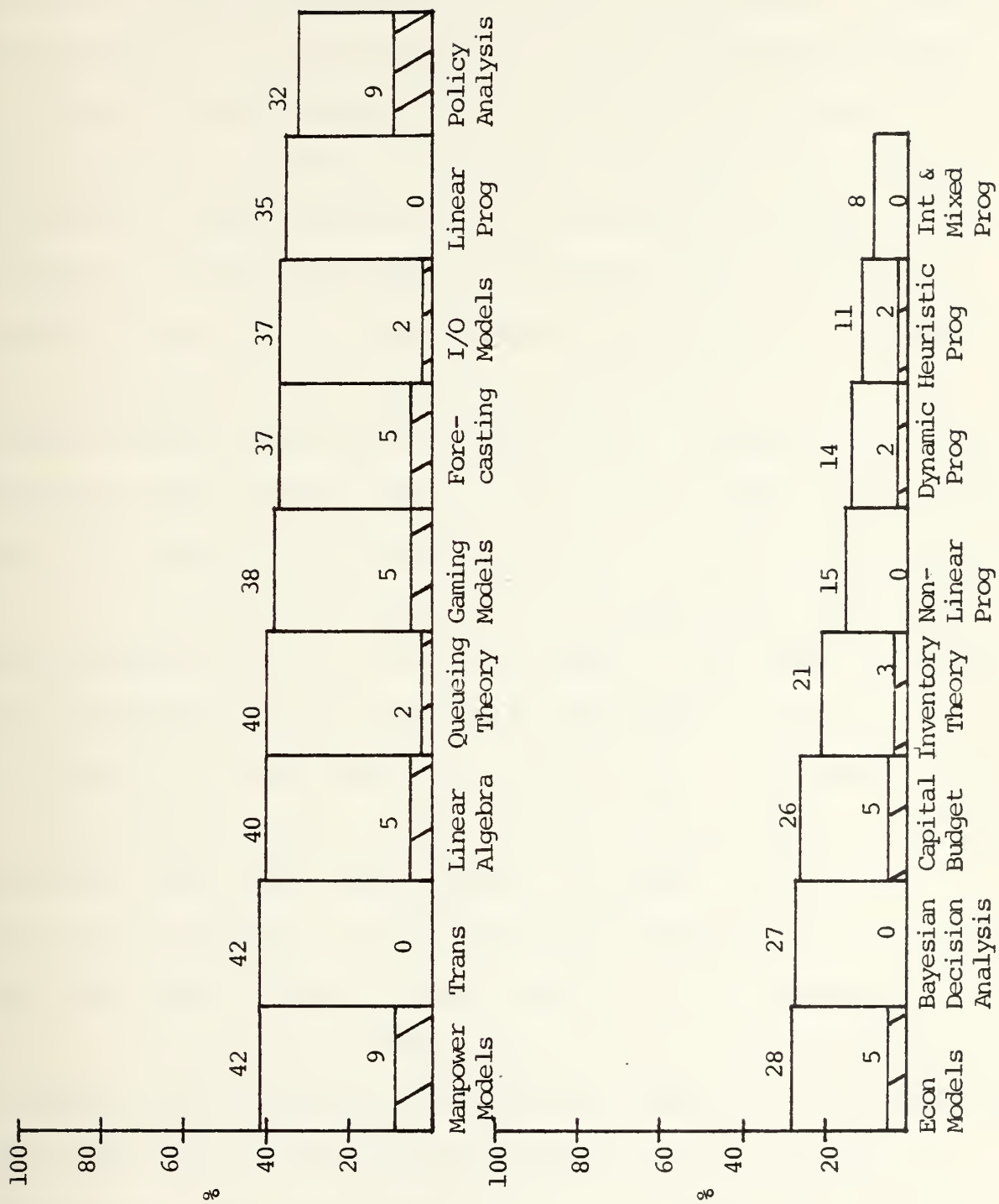


Figure 1 (CONTINUED)

H. IMPORTANCE OF OR TECHNIQUES

In question 8 of the survey individuals were asked to record the relative importance to them on a scale of 1 = Extremely Important to 5 = Not Important of having a working knowledge of the 35 listed OR techniques and application areas in meeting the daily requirements of their 9650 billets. The complete listing of answer frequencies is contained in Appendix B while Figure 2 includes bar graphs representing the cumulative response frequencies for each subject. The surveyed techniques and application areas comprise the horizontal axes of the graphs and the percentage of individuals responding are represented by the vertical axes. The clear enclosed columns represent the cumulative percentage of individuals who marked a "1", "2" or "3" (extremely important to average importance) next to each subject while the remaining portion left blank represents the percentage of individuals who indicated a "4" or a "5" (little or no importance) as their answer. For example, Figure 2 shows that a total of 77% of the 66 billet-holders responding said that they felt that Probability Theory fell in the "1", "2" or "3" category of their individual importance scales while 23% felt that it held a lower position on their scales ("4" or "5"). It can be seen that, as was the case in usage frequency, Parametric Data Analysis, Probability Theory, Cost Effectiveness and Networks hold the highest positions in an ordering of importance based upon answers of "1", "2" and "3" while the advanced mathematical programming methods (Non-linear, Heuristic, Dynamic, Integer and Mixed Programming) hold the lowest.

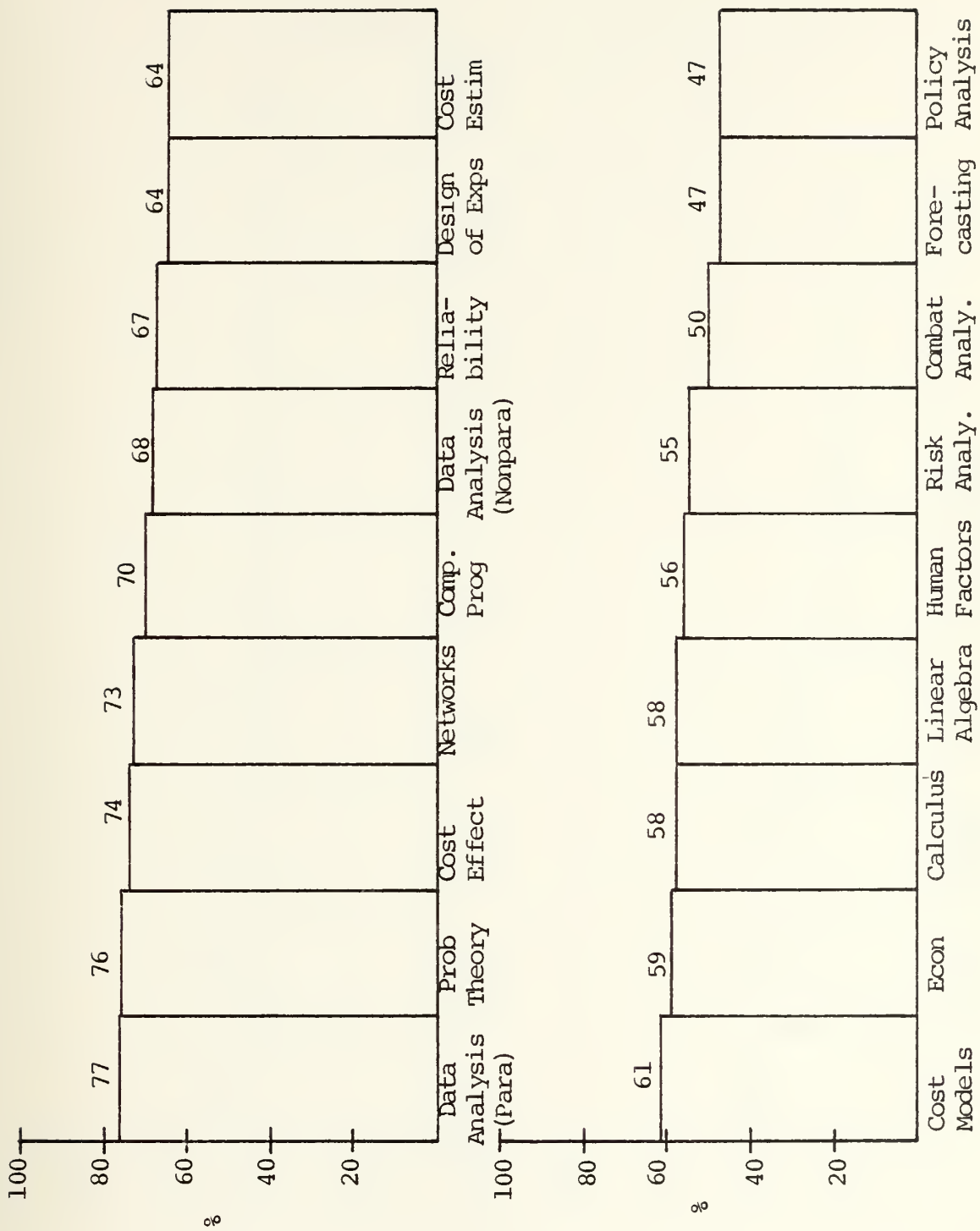


Figure 2. IMPORTANCE OF OR TECHNIQUES

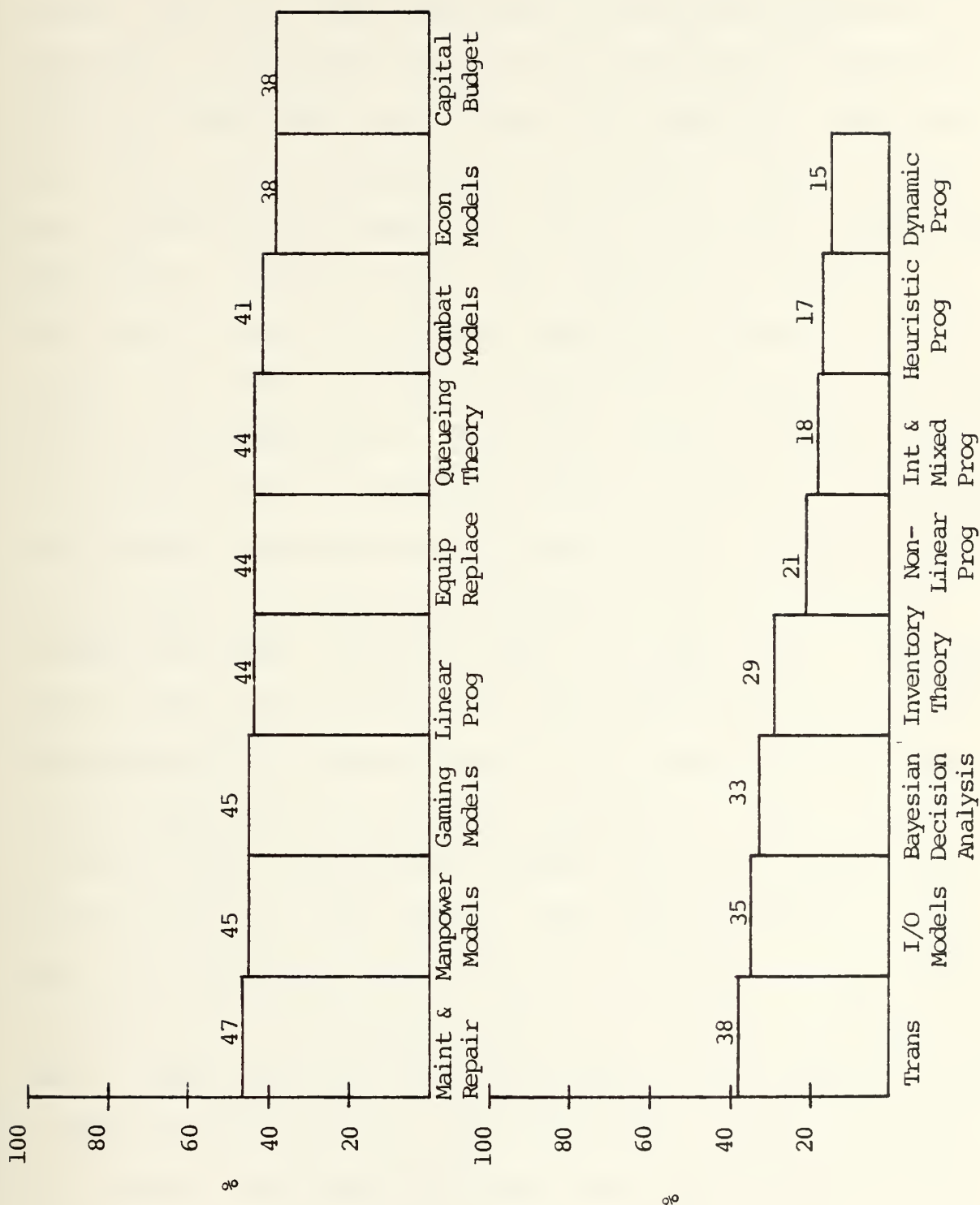


Figure 2 (CONTINUED)

I. IMPORTANCE AND USAGE FREQUENCY COMPARISONS

If we take responses "1", "2" and "3" from question 8 to mean Extremely Important, Very Important and Average Importance, respectively, we can order the listed techniques by importance. Combining "Sometimes" and "Always" from question 7 also allows us to order these techniques by frequency of usage. We can, then, compare order based upon frequency of usage ("Sometimes" and "Always") (Table X) with order based upon frequency of importance (average or greater importance) (Table XI). It appears that there is a strong correlation between utilization and perceived importance. The only individual subjects that do not fall within a reasonable number of places on both lists are Equipment Replacement and Transportation (which are higher on the usage list than on the importance list) and Linear Algebra and Policy Analysis (which are higher on the importance list). This may indicate that, while Equipment Replacement and Transportation are applied quite often, they do not seem to be very important to the using individuals. Additionally, it may be that, while Linear Algebra and Policy Analysis may not be used very often, when it does become necessary to use them, it is important to know how to use them. Another possible explanation for the subjects which fall lower on the usage list than on the importance list is the imperative of knowing where a technique does not fit. The implication is that, knowledge of a certain technique and knowing when not to use it can be just as important as knowing when to use it.

TABLE X

ORDER BY FREQUENCY OF USAGE

<u>Subject</u>	<u>Percentage (Sometimes + Always)</u>
Data Analysis (Parametric)	81
Cost Effectiveness	80
Networks, Flows and Graphs	79
Probability Theory	77
Cost Estimation	73
Design, Conduct and Evaluation of Experiments	70
Data Analysis (Nonparametric)	67
Reliability	62
Computer Programming	58
Human Factors	53
Cost Models	53
Equipment Replacement	52
Economics	51
Calculus	51
Maintenance and Repair	51
Combat Analysis	49
Risk Analysis	45
Combat Models	44
Manpower Models	42
Transportation	42
Linear Algebra	40
Queueing Theory and Stochastic Models	40
Gaming Models	38
Forecasting	37
Input-Output Models	37
Linear Programming	35
Policy Analysis	32
Econometric Models	28
Bayesian Decision Analysis	27
Capital Budgeting	26
Inventory Theory	21
Non-linear Programming	15
Dynamic Programming	14
Heuristic Programming	11
Integer and Mixed Programming	8

TABLE XI
ORDER BY IMPORTANCE

<u>Subject</u>	<u>Percentage (Categories 1 + 2 + 3)</u>
Data Analysis (Parametric)	77
Probability Theory	76
Cost Effectiveness	74
Networks, Flows and Graphs	73
Computer Programming	70
Data Analysis (Nonparametric)	68
Reliability	67
Design, Conduct and Evaluation of Experiments	64
Cost Estimation	64
Cost Models	61
Economics	59
Calculus	58
Linear Algebra	58
Human Factors	56
Risk Analysis	55
Combat Analysis	50
Forecasting	47
Policy Analysis	47
Maintenance and Repair	47
Manpower Models	45
Gaming Models	45
Linear Programming	44
Equipment Replacement	44
Queueing Theory and Stochastic Models	44
Combat Models	41
Econometric Models	38
Capital Budgeting	38
Transportation	38
Input-Output Models	35
Bayesian Decision Analysis	33
Inventory Theory	29
Non-linear Programming	21
Integer and Mixed Programming	18
Heuristic Programming	17
Dynamic Programming	15

The association between importance and utilization of OR techniques was measured using the Spearman rank correlation coefficient. For the two lists in Tables X and XI a rank correlation coefficient of +0.918 was computed, indicating a highly positive correlation. Testing the null hypothesis that there is no relation in the reported order of usage frequency and the reported order of importance frequency of these OR subjects resulted in a P value of nearly zero, indicating that, at almost any level of significance, the null hypothesis of no relationship would be rejected.

J. USAGE BY OFFICER RANK

A comparison of usage frequencies was also analyzed by seniority of rank. Appendix C contains frequency tables based on reported usage of subjects for Captains/Majors and Lieutenant Colonels/Colonels. Figure 3 shows comparisons between Captains/Majors and Lieutenant Colonels/Colonels for reported usage frequencies for each of the listed OR techniques and application areas. The cross-hatched column over each subject indicates the percentage of Captains and Majors who reported using that subject either "Sometimes" or "Always" and the clear enclosed column indicates the percentage of Lieutenant Colonels and Colonels who reported using each subject "Sometimes" or "Always".

To determine the greater frequency of usage for individual techniques, two methods were utilized, the first method being an absolute difference technique. Because of the small number

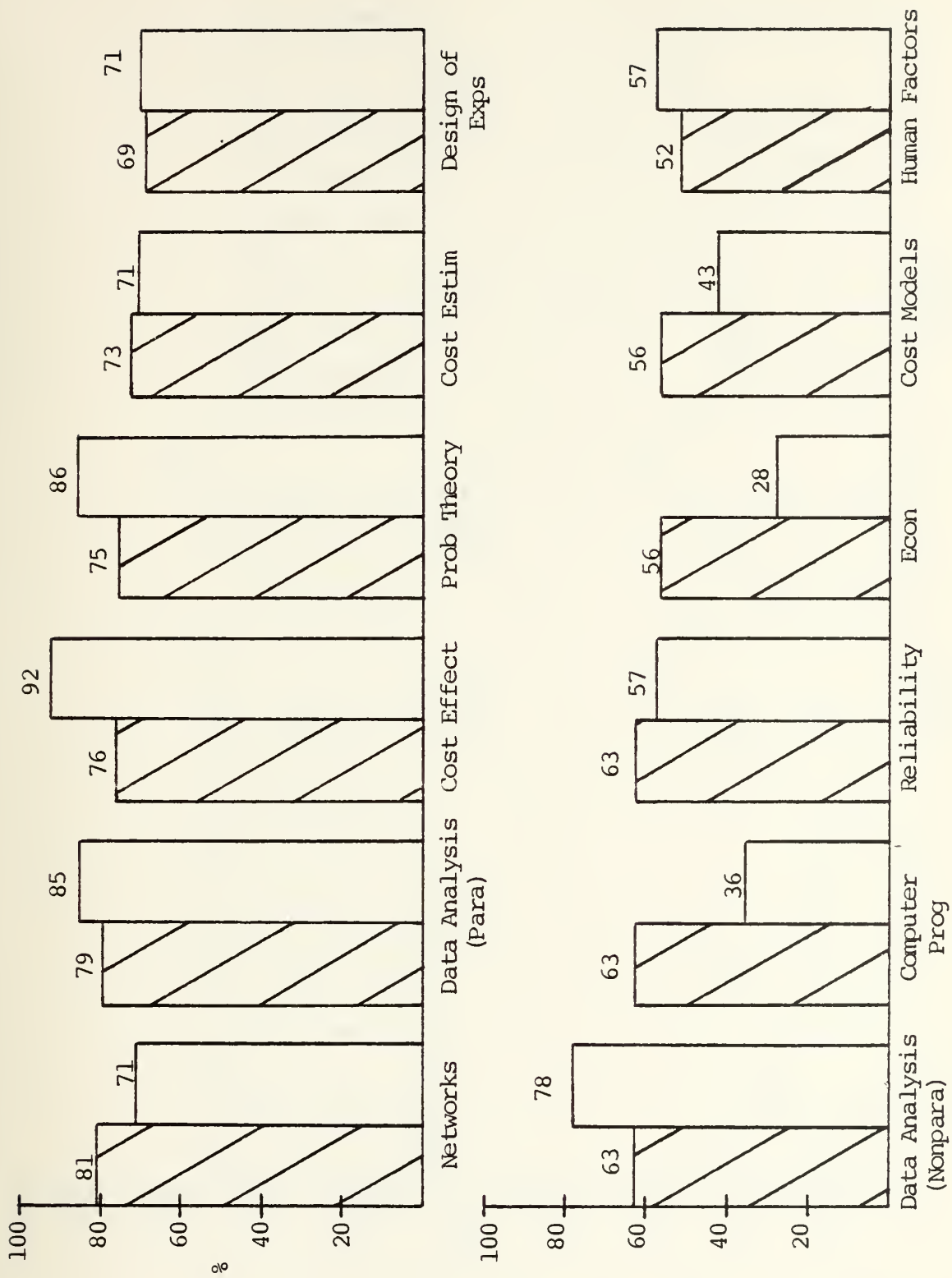


Figure 3. SERVICE RANK USAGE COMPARISON

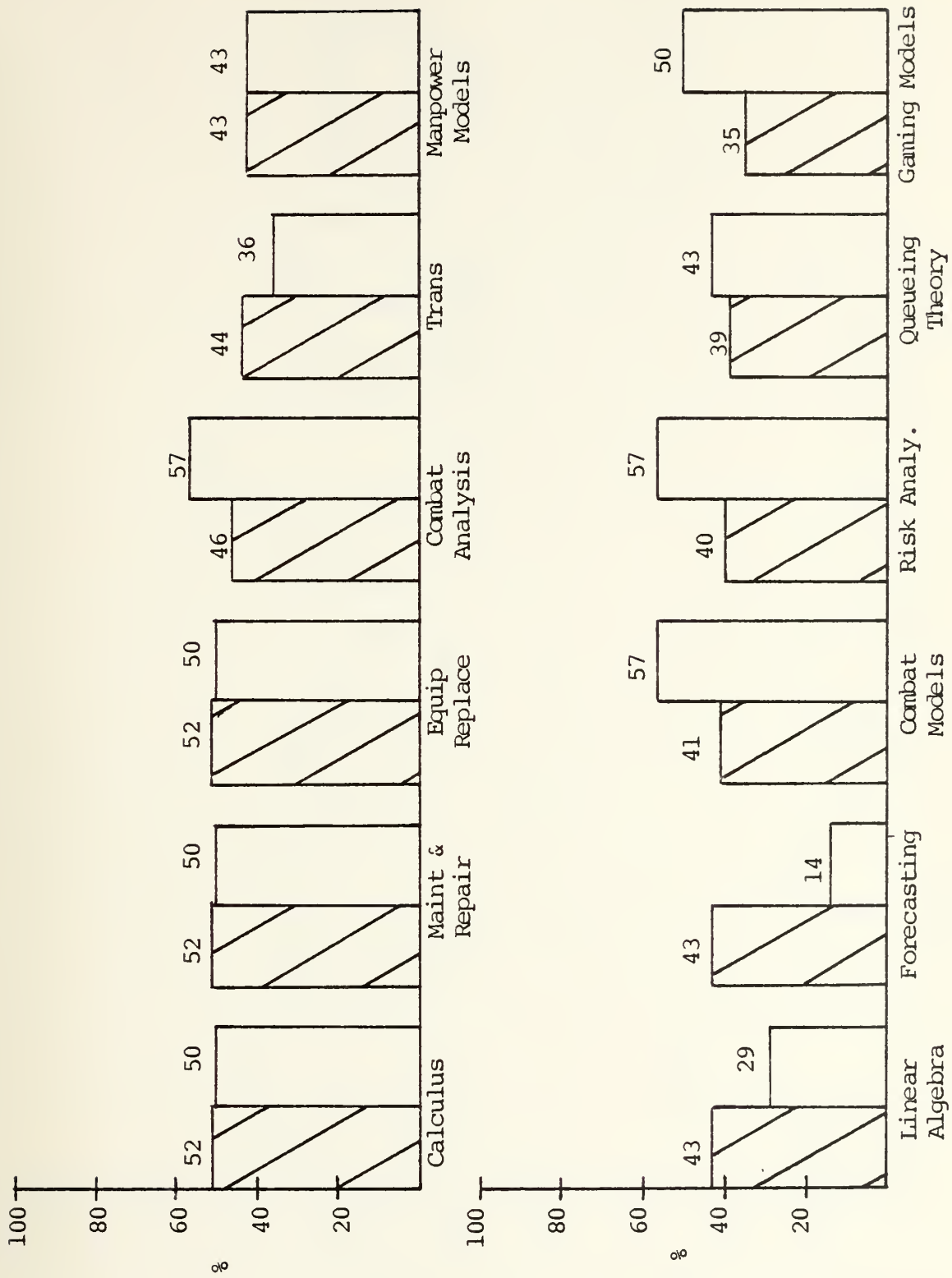


Figure 3. (CONTINUED)

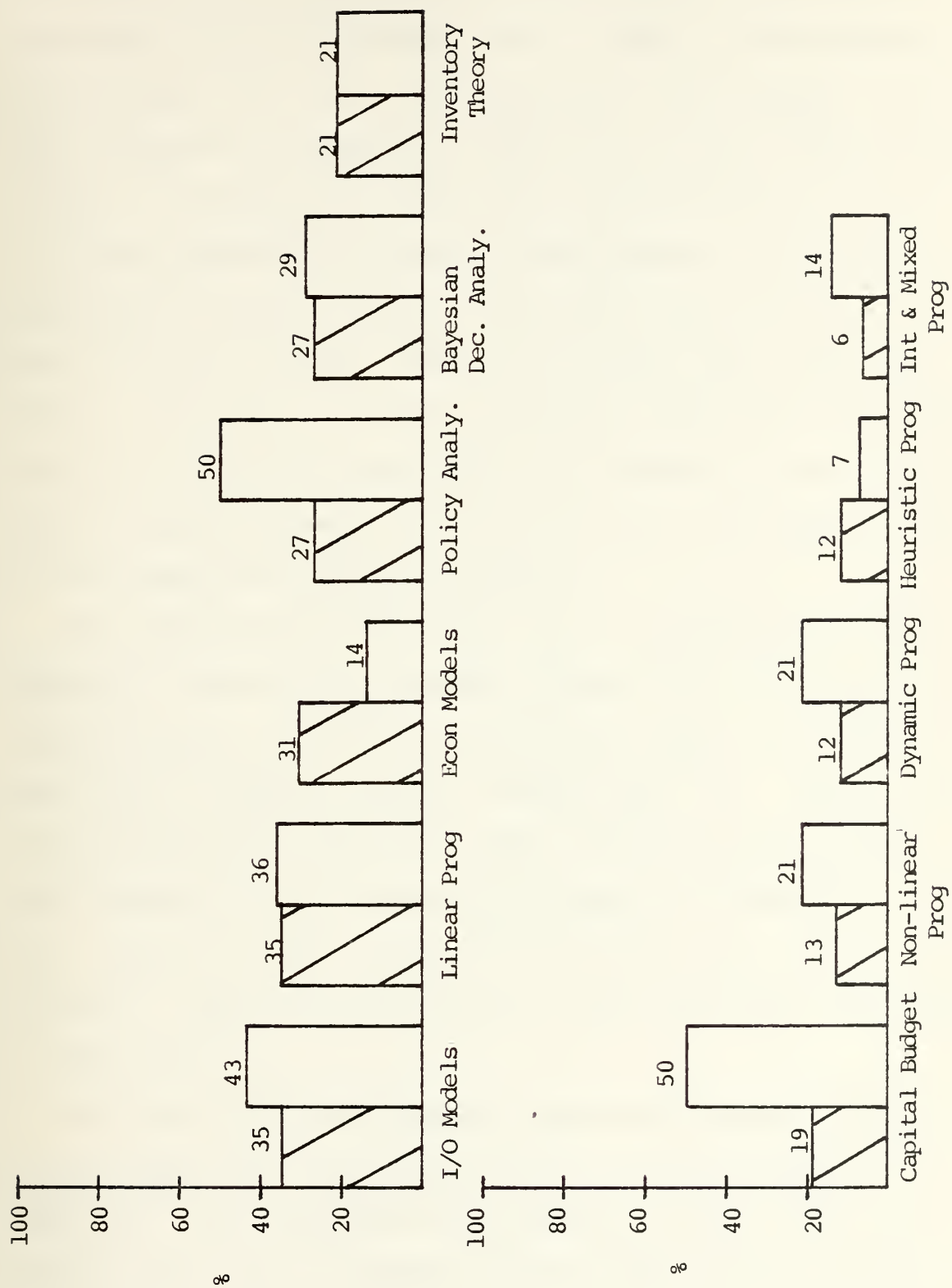


Figure 3. (CONTINUED)

of personnel who reported having held a 9650 billet as a Lieutenant Colonel or Colonel (14) a change in the answer of one of these men (e.g., from "Sometimes" to "Always") would mean a frequency difference of more than 7% for any particular subject. Therefore, an arbitrary absolute difference ($|\Delta|$) of 10% was chosen to indicate a "significant" difference in frequency of reported usage ("Sometimes" plus "Always") for each of the two groups. Thus, the service rank group that showed a value for $|\Delta|$ of 10% or more in reported usage frequency for any particular subject was deemed to have the greater reported usage frequency for that subject. The results obtained by this method are shown in Table XII.

The second comparison method was a relative difference approach. Reported frequencies ("Sometimes" plus "Always") for Captains/Majors, k , and for Lieutenant Colonels/Colonels, ℓ , were used to compute relative frequencies, k/ℓ . The values of k/ℓ above 1.25 (arbitrary) were judged to mean a higher usage frequency for Captains and Majors and those below 0.75 were judged as higher frequencies for Lieutenant Colonels and Colonels. The results obtained by this method are reflected in Table XIII.

Subjects that were indicated as being used with greater frequency by each rank group by both methods are shown in Table XIV. Two conclusions that might be drawn from this analysis are that it appears that the more junior officers are using economic theory and techniques (as well as Computer

TABLE XII

GREATER FREQUENCY OF USAGE BY OFFICER RANK
(ABSOLUTE DIFFERENCE)

<u>Captains/Majors</u>		<u>Lieutenant Colonels/Colonels</u>	
<u>Technique</u>	<u> Δ %</u>	<u>Technique</u>	<u> Δ %</u>
Forecasting	29	Capital Budgeting	31
Economics	28	Policy Analysis	23
Computer Programming	27	Risk Analysis	17
Econometric Models	17	Cost Effectiveness	16
Linear Algebra	14	Combat Models	16
Cost Models	13	Data Analysis	
Networks, Flows and		(Nonparametric)	15
Graphs	10	Gaming Models	15
		Probability Theory	11
		Combat Analysis	11

TABLE XIII

GREATER FREQUENCY OF USAGE BY OFFICER RANK
(RELATIVE DIFFERENCE)

<u>Captains/Majors</u>		<u>Lieutenant Colonels/Colonels</u>	
<u>Technique</u>	<u>k/l</u>	<u>Technique</u>	<u>k/l</u>
Forecasting	3.071	Capital Budgeting	0.380
Econometric Models	2.214	Integer and Mixed	
Economics	2.000	Programming	0.429
Computer Programming	1.750	Policy Analysis	0.540
Heuristic Programming	1.714	Dynamic Programming	0.571
Linear Algebra	1.483	Nonlinear Programming	0.619
Cost Models	1.302	Gaming Models	0.700
		Risk Analysis	0.702
		Combat Models	0.719

TABLE XIV

GREATER FREQUENCY OF USAGE BY OFFICER RANK
(BOTH METHODS)

<u>Captains/Majors</u>		<u>Lieutenant Colonels/Colonels</u>	
<u>Technique</u>		<u>Technique</u>	
Forecasting		Capital Budgeting	
Economics		Policy Analysis	
Econometric Models		Risk Analysis	
Computer Programming		Gaming Models	
Linear Algebra		Combat Models	
Cost Models			

Programming and Linear Algebra) more often than their seniors are and that the senior officers are more involved with the budgeting of funds and the development of policy than are the junior officers (as one might expect).

K. BREADTH OF USAGE BY OFFICER RANK

Having studied the differences between service rank groups in regard to usage frequency of individual OR techniques and application areas, we now look at whether there is a difference between the two officer groups based upon overall breadth of usage of the listed subjects. An index of breadth of usage was created by computing an average usage score for each individual in the following manner: a value of 1, 2 or 3 was assigned to each box marked "Always", "Sometimes" or "Never", respectively, in question 7 and these were summed over all techniques and application areas. This sum was then divided by 35, the total number of OR subjects listed. For example, an individual questionnaire with question 7 having 10 subjects marked as being used "Always", 15 subjects marked as being used "Sometimes" and 10 subjects marked as being used "Never" would result in an average usage score of $\frac{(10 \cdot 1) + (15 \cdot 2) + (10 \cdot 3)}{35} = 2.0$ for that particular individual.

The complete list of all individual average scores was divided into two independent samples based upon service rank (Captains/Majors and Lieutenant Colonels/Colonels). A Kolmogorov-Smirnov (K-S) two-sample test was set up to test the null hypothesis that there is no difference between Captains/Majors

and Lieutenant Colonels/Colonels based upon breadth of usage of the OR techniques and application areas listed in question 7 of the survey. Simply stated, a K-S test determines if the cumulative distributions of the two samples are sufficiently divergent to suggest that the samples come from different populations.

The sizes of the samples in this case varied from relatively large (52 Captains and Majors) to relatively small (14 Lieutenant Colonels and Colonels). Since adequate statistical tables for the K-S test statistic were not available for a mixture of large and small samples, two-tailed tests for both small and large samples were conducted resulting in acceptance of the null hypothesis.

L. IMPORTANCE BY OFFICER RANK

Examination of these same 35 subjects with regard to the perceived importance to the two service rank groups (Captains/Majors and Lieutenant Colonels/Colonels) resulted in the frequency tables presented in Appendix D. Figure 4 exhibits comparisons for each of the listed techniques and application areas for these two groups. The cross-hatched column over each subject indicates the percentage of Captains and Majors who reported an importance level of "1", "2" or "3" (average or more importance) for that subject and the clear enclosed columns denote the percentage of Lieutenant Colonels and Colonels who reported an importance level of "1", "2" or "3" for each subject.

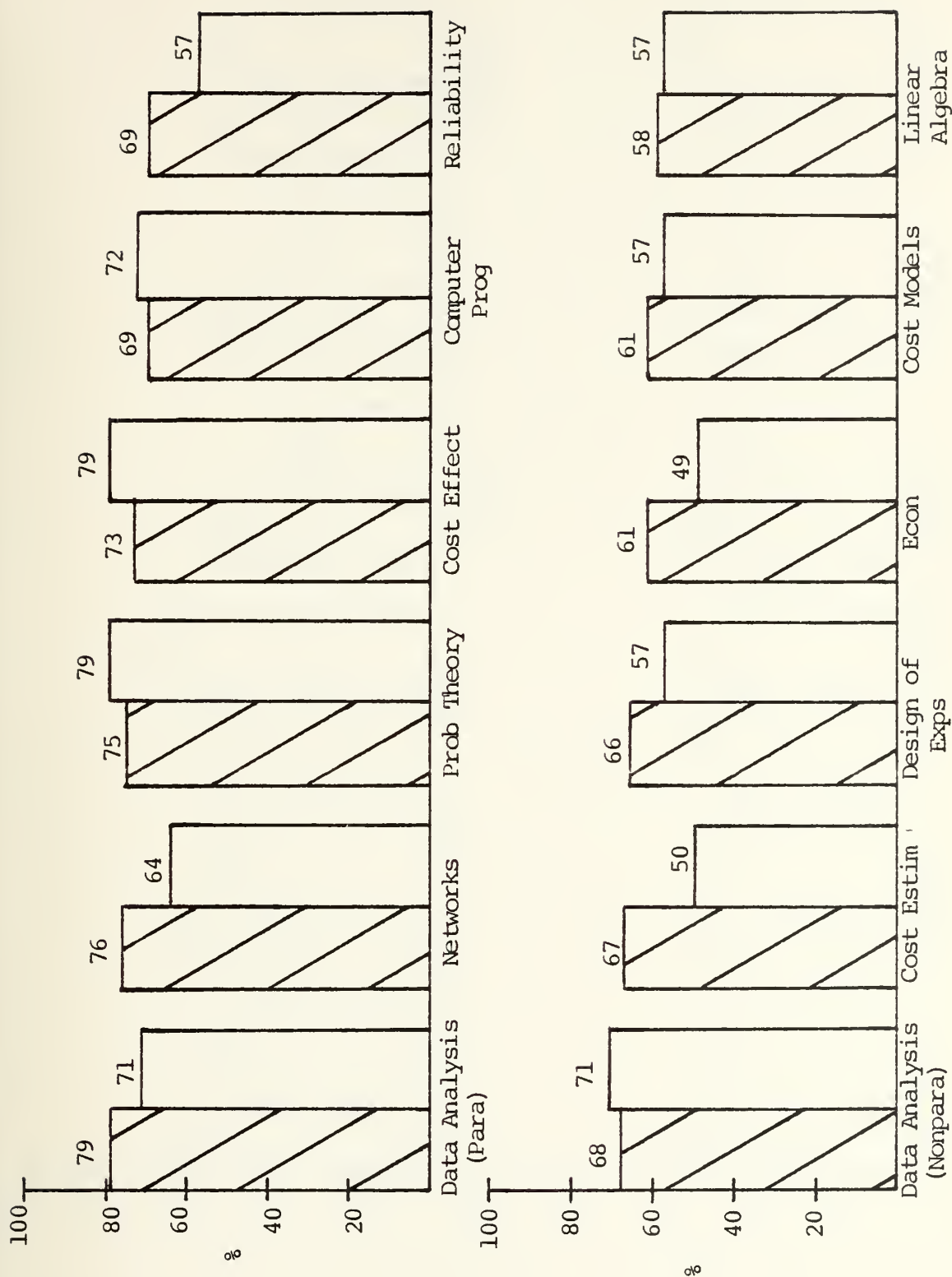


Figure 4. SERVICE RANK IMPORTANCE COMPARISON

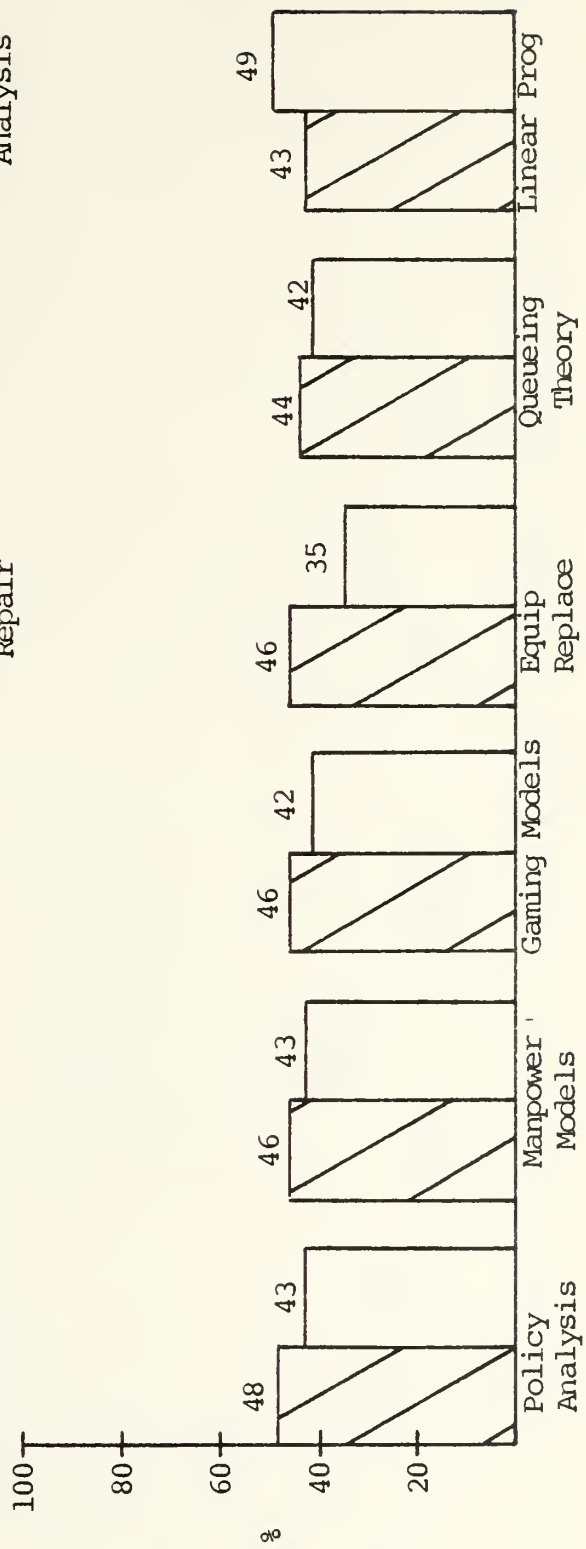
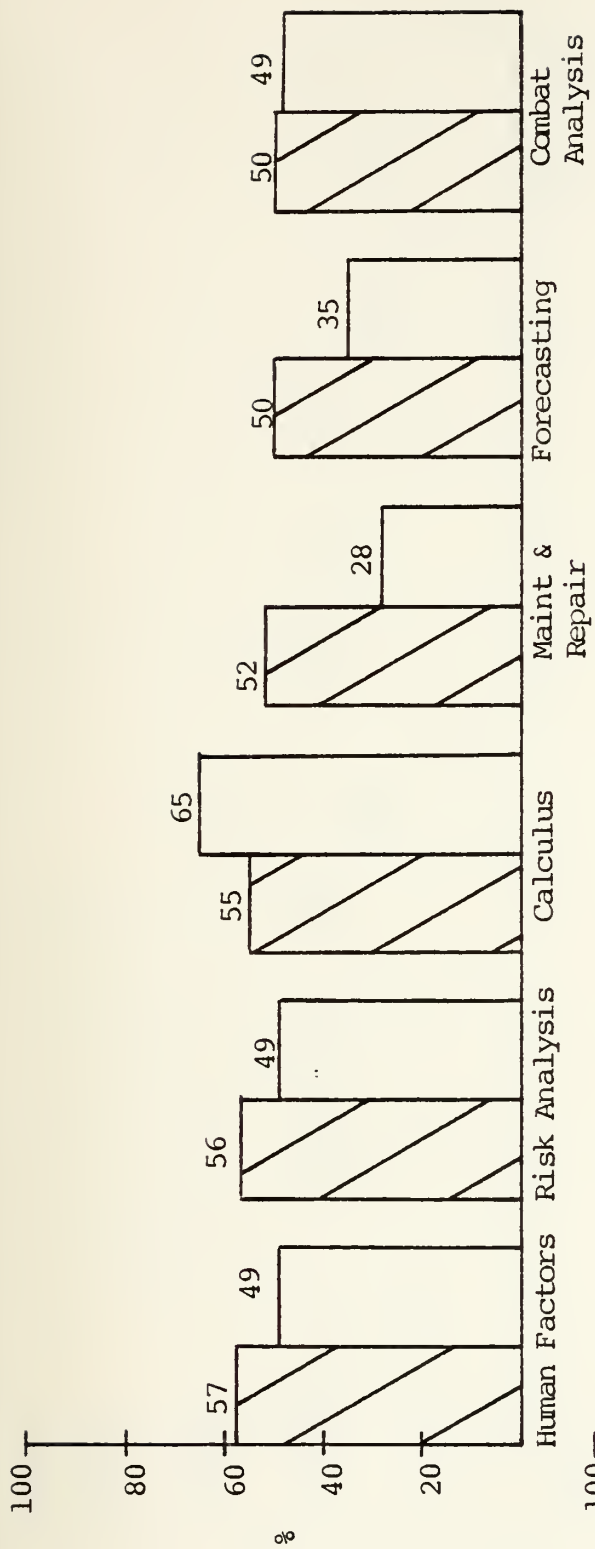


Figure 4. (CONTINUED)

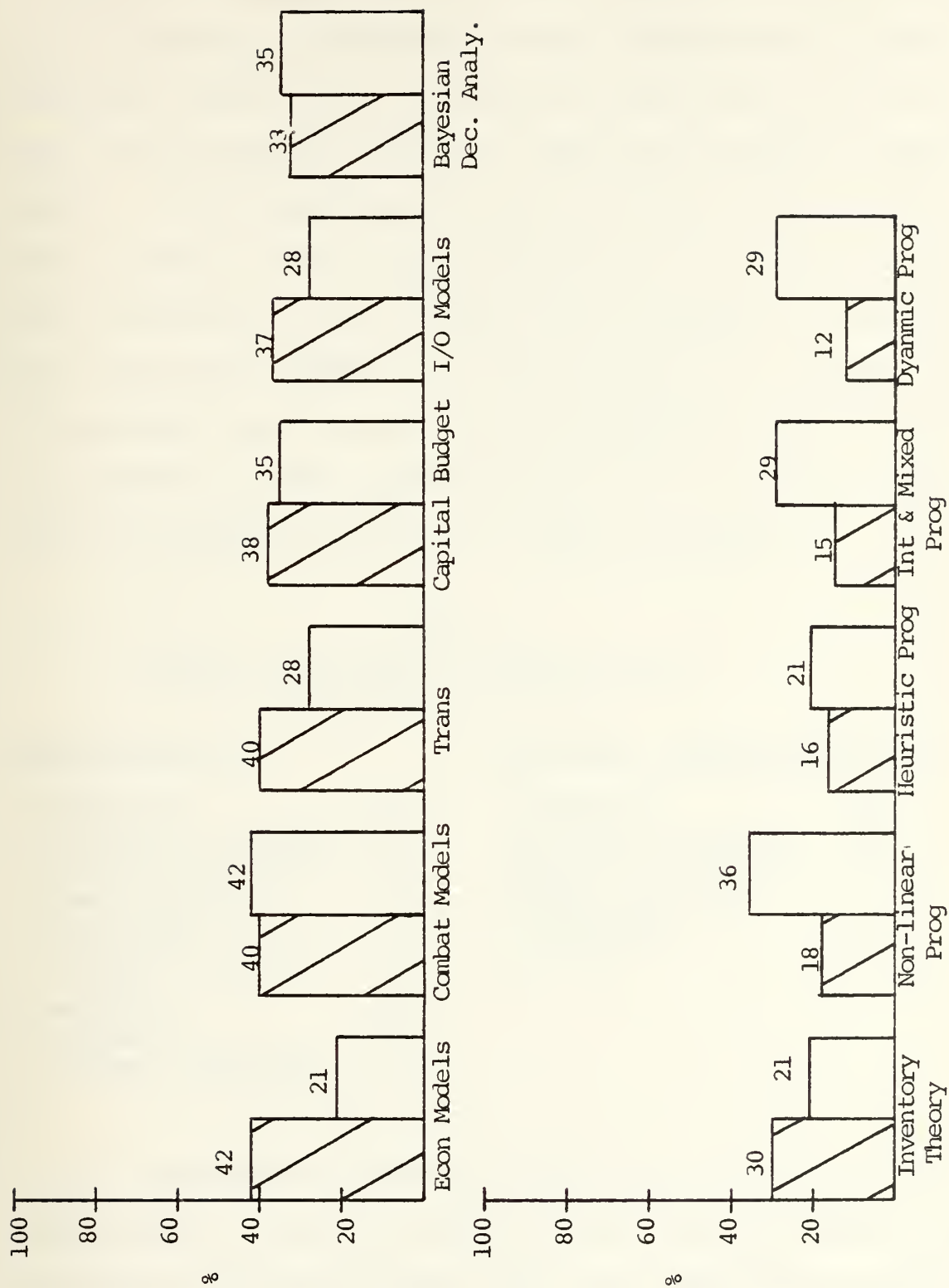


Figure 4. (CONTINUED)

Absolute and relative difference methods similar to those used to determine frequency of usage differences were used to determine "significant" differences between the two officer rank groups regarding perceived importance of each OR technique. For the absolute difference method, it was decided that the service rank group displaying a 10% or greater absolute difference, ($|\Delta|$), in cumulative frequency of average-or-more-importance answers ("1" plus "2" plus "3") for any listed OR technique would be sufficient to indicate that that subject was regarded as more important by one of the officer ranks. Table XV reflects the results of this procedure.

TABLE XV

GREATER IMPORTANCE BY OFFICER RANK
(ABSOLUTE DIFFERENCE)

<u>Captains/Majors</u>		<u>Lieutenant Colonels/Colonels</u>	
<u>Technique</u>	<u>Δ%</u>	<u>Technique</u>	<u>Δ%</u>
Maintenance and Repair	24	Nonlinear Programming	18 -
Econometric Models	21	Dynamic Programming	17
Cost Estimation	17	Integer and Mixed	
Forecasting	15	Programming	14
Networks, Flows and		Calculus	10
Graphs	12		
Reliability	12		
Economics	12		
Equipment Replacement	11		

For the relative difference approach, ratios of cumulative frequencies ("1" plus "2" plus "3") for Captains/Majors over Lieutenant Colonels/Colonels (k/ℓ) were computed for each of the listed OR techniques. Those techniques having a k/ℓ ratio of 1.25 or higher were considered to be of greater

importance to the Captains and Majors. Those techniques displaying a ratio of 0.75 or lower were deemed to be of greater importance to the Lieutenant Colonels and Colonels. The results obtained by using this method are displayed in Table XVI.

TABLE XVI

GREATER IMPORTANCE BY OFFICER RANK
(RELATIVE DIFFERENCE)

<u>Captains/Majors</u>		<u>Lieutenant Colonels/Colonels</u>	
<u>Technique</u>	<u>k/l</u>	<u>Technique</u>	<u>k/l</u>
Econometric Models	2.000	Dynamic Programming	0.414
Maintenance and Repair	1.857	Nonlinear Programming	0.500
Inventory Theory	1.429	Integer and Mixed	
Forecasting	1.429	Programming	0.517
Transportation	1.429		
Cost Estimation	1.340		
Input-Output Models	1.321		
Equipment Replacement	1.314		

Subjects which were included on both lists are shown in Table XVII. It appears from this table that economic techniques and equipment-related applications are perceived to be more important to the Captains and Majors while the advanced

TABLE XVII

GREATER IMPORTANCE BY OFFICER RANK
(BOTH METHODS)

<u>Captains/Majors</u>		<u>Lieutenant Colonels/Colonels</u>	
<u>Technique</u>		<u>Technique</u>	
Cost Estimation		Nonlinear Programming	
Econometric Models		Dynamic Programming	
Forecasting		Integer and Mixed Programming	
Equipment Replacement			
Maintenance and Repair			

mathematical techniques are held in higher esteem by the more senior officers.

M. BREADTH OF IMPORTANCE BY OFFICER RANK

Next, the question of a difference between the two service rank groups based upon perceived importance to the individuals of the entire list of OR techniques (i.e., the "breadth of importance") was addressed. An index of the breadth of importance was created and, once again, a Kolmogorov-Smirnov two-sample test was used. An average importance score for each individual was computed by assigning a value of 1, 2, 3, 4 or 5 to each box marked "1", "2", "3", "4" or "5" in question 8, then summing the values over all techniques listed and dividing by 35. The average importance scores were then divided into two groups based on the service rank of each individual and a two-tailed K-S test for two independent samples was conducted resulting in acceptance of the null hypothesis. The implication of this test is that there is no difference between Captains/Majors and Lieutenant Colonels/Colonels in regard to their perceived feelings of importance of all of the listed OR techniques and application areas as a whole.

N. BREADTH OF USAGE BY FUNCTIONAL AREA

Having found no differences in either overall breadth of usage or overall breadth of importance of the listed subjects based upon the seniority of the respondents, the association of breadth of usage and functional area of the respondents was

next inspected. Respondents' average usage scores, as determined by the method described above, were partitioned into the following general function areas: "Manpower", "Logistics", "Operations and Plans", "Test and Evaluation", "Aviation", "Combination" and "Other". A Kruskal-Wallis one-way analysis of variance was then employed to test the null hypothesis: there is no difference between overall breadths of usage of the OR techniques for individuals employed in the above-listed general function areas. The Kruskal-Wallis one-way analysis of variance was chosen for use because it requires only that the variable measurement be (at least) ordinal and that the variable have an underlying continuous distribution. In addition, the Kruskal-Wallis test is more efficient than some other nonparametric tests of population differences because it uses more of the information in the observations by preserving the magnitude of the individual scores [Ref. 14:pp. 193-194]. Utilizing this test and correcting for the effect of ties in the observations [Ref. 14:p. 188], a test statistic of 13.52 was computed. This statistic is approximately χ^2 distributed with 6 degrees of freedom and yields a P value of 0.035. Thus, the null hypothesis is rejected, meaning that there is a difference between individuals (when they are grouped according to the functional area of their billets) based upon their overall usage of all of the listed OR techniques.

Close examination of the means of the average usage scores for each function area (displayed in Table XVIII) may help us understand a possible cause for this null hypothesis rejection. The

TABLE XVIII

FUNCTION AREA MEAN USAGE SCORES

<u>Function Area</u>	<u>Mean Usage Score</u>	<u>Sample Size</u>
Combination	2.222	8
Aviation	2.405	6
Manpower	2.439	11
Test and Evaluation	2.472	14
Operations and Plans	2.543	7
Logistics	2.589	8
Other	2.590	12

mean of the average usage scores for each function area may be interpreted to represent a measure of the overall breadth of usage of the listed subjects by individuals employed in each of these general areas. The closer a group's mean usage score is to 1.0, the higher the overall frequency of usage of OR techniques by the individuals in that functional area (recall that "Always" = 1, "Sometimes" = 2 and "Never" = 3). There is a notable difference in mean breadth of usage for the groups, especially in the case where individuals worked in a combination of functional areas. Intuitively, we might expect that individuals working in a combination of functional areas would be apt to use OR techniques more than those whose work might be channeled into one particular area.

O. BREADTH OF IMPORTANCE BY FUNCTIONAL AREA

The same method as described in the previous section was employed to test for differences of breadths of importance of

the subjects to individuals employed in the function areas listed above. A P value of 0.036 was obtained, thus, again, causing rejection of the null hypothesis of no difference. Looking at the mean importance scores for each function area (displayed in Table XIX) helps to explain this rejection. A low score implies a high overall perception of importance of the listed subjects while a high score implies a low overall feeling of importance (recall that Extremely Important = 1 and Not Important = 5). Once again we see a high variance of mean scores, ranging from 2.636 for those individuals working in a combination of functional areas to 3.912 for those working in the field of Logistics, and again, intuitively, we might expect that those individuals whose work is not confined to a particular area would be more apt to feel that, overall, OR techniques are more important than those individuals restricted to working in a specific field.

TABLE XIX

FUNCTION AREA MEAN IMPORTANCE SCORES

<u>Function Area</u>	<u>Mean Importance Score</u>	<u>Sample Size</u>
Combination	2.636	8
Manpower	3.301	11
Aviation	3.357	6
Test and Evaluation	3.400	14
Other	3.500	12
Operations and Plans	3.845	7
Logistics	3.912	8

P. BREADTH OF USAGE BY TYPE OF OR WORK DONE

The same procedures as described above were used to test for differences between overall breadth of usage and overall breadth of importance based upon the following types of OR work that the respondents reported doing the most:

Original OR work

Reviewing OR work done outside their section

Any combination of the types of OR work listed in question
4 of the survey

Any other type of OR work

None.

The average usage scores for all respondents were divided up into these five groups and a Kruskal-Wallis one-way analysis of variance test was conducted for the following null hypothesis: there is no difference in breadth of usage of OR techniques for individuals required to do the above-stated types of OR work the most. A test statistic of 12.36 was obtained (having corrected for tied observations) resulting in a P value of 0.015, causing a rejection of the null hypothesis. This means that there is a difference in breadth of usage of OR techniques between individuals doing different types of OR work. It can be seen from Table XX that mean usage scores varied from 2.378 (relatively high usage of the techniques) for the group doing original OR work to 2.743 (relatively low usage of the techniques) for the group doing no OR work. This would seem to intuitively support the statistical findings of the test.

TABLE XX

MEAN USAGE SCORES BY TYPE OF OR WORK DONE

<u>Type of OR Work</u>	<u>Mean Usage Score</u>	<u>Sample Size</u>
Original	2.378	22
Other	2.4	10
Review	2.513	23
Combination	2.567	6
None	2.743	5

It is interesting to note that, while five individuals reported in question 4 that they did not do any OR work, they went on in question 7 to report that they used at least some of the listed OR techniques either "Sometimes" or "Always".

Q. BREADTH OF IMPORTANCE BY TYPE OF OR WORK DONE

The Kruskal-Wallis test was also employed to test for no difference of breadth of importance of the listed subjects for the individuals required to do the above-listed types of OR work the most. A P value of 0.068 was obtained, causing null hypothesis acceptance at the 0.05 level. This means that, while individuals may use the OR techniques to varying degrees based upon the type of work they do, there is not a significant degree of disagreement between these individuals based upon the overall perceived importance of knowing how to use (and when not to use) these techniques.

R. ADDITIONAL OR TECHNIQUES

Numerous OR techniques and general subject areas were mentioned by the respondents when asked what techniques they used in addition to those listed in the questions. These subjects can be separated into four general categories:

Management and Communications

Problem Solving Procedures

System Development

Computer Science

Twenty-five people expressed an importance for knowledge in the areas of Management and Communications. (Management techniques, contract management, general decision analysis, bureaucratic realities, management information systems, public speaking, technical report writing, communications systems, salesmanship, information theory and data communications were a few of the subjects specifically mentioned.) Fifteen individuals listed subjects that might be incorporated under the general heading of Problem Solving Procedures. These included problem definition, data collection, quality control, data processing fundamentals, measures of effectiveness, scaling techniques and common sense. Subjects possibly encompassed by the title System Development were mentioned by 12 respondents. These subjects included system design, system acquisition, the Planning, Programming and Budgeting System and systems analysis. Finally, 9 individuals felt that specialized knowledge in the field of computers was of great assistance in aiding them in

the performance of their duties. Specifically, they listed computer modeling, computer program design, computer applications and computer system design as being important to them.

S. TIME SPENT DOING OR WORK

When asked what percentage of their work they actually spend doing OR work in comparison to their other duties, the personnel surveyed responded as shown in Table XXI. Overall, it appears that the great majority of those answering (78.9%) spend twenty-five to seventy-five percent of their time in the actual conduct of Operations Research. In addition, using a χ^2 test for two independent samples, the null hypothesis that there is no difference between Captains/Majors and Lieutenant Colonels/Colonels based upon percentage of work time actually spent doing OR work was tested. The resultant P value of 0.471 indicates acceptance of the null hypothesis, indicating that there is not a significant difference between the amount of work time spent by the more senior officers in performing OR-related tasks

TABLE XXI

PERCENT OF WORK TIME ACTUALLY SPENT DOING OR WORK

<u>Percent</u>	<u>Captains/Majors</u>	<u>Lieutenant Colonels/Colonels</u>	<u>Total</u>
0	8 (15.4)	2 (14.3)	10 (15.1)
25	12 (23.1)	5 (35.7)	17 (25.8)
50	12 (23.1)	5 (35.7)	17 (25.8)
75	16 (30.8)	2 (14.3)	18 (27.3)
100	<u>4 (7.7)</u>	<u>0 (0.0)</u>	<u>4 (6.1)</u>
Totals	52 (100)	14 (100)	66 (100)
Ave. Time Spent	54.3%	37.5%	45.8%

and the amount of work time spent by Captains and Majors in these types of endeavors.

The percentage-of-work-time-spent data was also partitioned into groups based upon general function area as shown in Table XXII. While it is true that a χ^2 test should not be performed on this partitioning due to the fact that 23% of the expected frequencies fall below 1.0 and all are below 5.0, the wide variance of average time spent by individuals employed in each function area (from 12.5% for those involved in Logistics to 78.1% for those placing their jobs in the category of a combination of function areas) suggest that there is a difference between individuals employed in each of the listed function

TABLE XXII

FUNCTIONAL AREA VERSUS PERCENT OF WORK TIME SPENT DOING OR WORK

	Manpower	Logistics	Operations and Plans	Test and Evaluation	Aviation	Combination	Other	Total
0%	2	4	3	0	0	0	1	10
25%	1	4	2	3	2	0	5	17
50%	5	0	1	5	3	1	2	17
75%	3	0	1	4	1	5	4	18
100%	<u>0</u>	<u>0</u>	<u>0</u>	<u>2</u>	<u>0</u>	<u>2</u>	<u>0</u>	<u>4</u>
Total	11	8	7	14	6	8	12	66
Average Time Spent	45.5	12.5	25.0	58.9	33.3	78.1	43.75	

areas based upon the percentage of work time actually spent doing OR work.

Of the 27 individuals who reported spending 25% or less of their work time performing explicit OR functions, 9 stated that the majority of their time was spent performing general management functions, 7 reported that studies review or policy review (that did not require explicit OR work) consumed most of their time, 4 reported administrative duties and 3 said working with computers kept them busy most of the time.

T. ACCEPTANCE OF OR WORK BY SUPERIORS

Table XXIII contains the results of the response when individuals were asked to relate the basic level of acceptance of OR work by their superiors. As can be seen, the majority reported that OR work is usually accepted while none of the respondents said that OR work is never accepted. A χ^2 test was used to test the null hypothesis that there is no

TABLE XXIII
OR WORK ACCEPTANCE LEVEL

<u>Acceptance Level</u>	<u>Captains/Majors</u>	<u>Lt. Colonels/Colonels</u>	<u>Total</u>
Accepted w/o Question	10 (20.4)	4 (28.6)	14 (22.2)
Usually Accepted	35 (71.4)	9 (64.3)	44 (69.8)
Rarely Accepted	4 (8.2)	1 (7.1)	5 (7.9)
Never Acceptor	<u>0 (0.0)</u>	<u>0 (0.0)</u>	<u>0 (0.0)</u>
Totals	49 (100) *	14 (100)	63 (100) *

* Note: 3 individuals failed to answer the question.

difference between Captains/Majors and Lieutenant Colonels/Colonels based upon the acceptance level of OR work of those for whom they work. (The category of "Never accepted" was dropped from the test since the number of observations from both samples for this category was zero.) A P value of 0.81 was obtained, resulting in acceptance of the null hypothesis. Thus, it appears that the acceptance level of OR work as perceived by the respondents is independent of the service rank of those proffering it.

IV. COMMENT ANALYSIS

The analysis described in the previous section relates directly to the first eleven survey questions, all of which can be described as being of a quasi-objective nature. Question 12, an open-ended solicitation of comments, resulted in billet utilization recommendations which can only be characterized as subjective. For this reason, the results obtained from question 12 will be discussed in this separate chapter.

One should bear in mind when reading this analysis that in no case did a majority of the respondents address any single subject. Rather, all topic discussions have been derived from the comments made by two to, at most, thirteen individuals. The author's intent in this chapter is to relate to the reader not so much the general consensus of the entire sample population as it is to give the flavor and substance of the returned comments. In this manner it is possible to illuminate some of the underlying issues regarding the use of Operations Analysts and, hence, to make possible recommendations for policy changes.

The most enlightening notion that question 12 evoked was that Operations Research is really a way of thinking which should be required of all Marine officers. Many respondents found their OR backgrounds to be almost as valuable to them in their assignments as line officers as in their SEP billet

tours. They felt that the real value of their advanced education was in providing them with an analytical method of formulating problems, thinking about causes and then determining their solutions in a systematic manner. Pure OR work is rare, they found, but techniques, such as mathematical programming, provide a good point of origin for thinking about specific problems (even though "a heuristic/seat-of-the-pants approach is what is actually required").

Many individuals also stated that there is an apparent lack of understanding on the part of many senior officers in managerial positions as to what Operations Research is and what analysts have been trained to do. This unawareness often leads to misuse of the analysts' technical skills or, worse, skepticism as to the validity of analytical work. Two officers reported that OR is often confused with Computer Science and, consequently, they spend much of their time writing and revising computer programs that are not related to analysis, while many respondents remarked upon the apparent suspicion among some senior officers in the Corps when operations analysis is suggested as a viable method of problem solving. Classical Operations Research techniques, such as those listed in the questionnaire, are often considered to be esoteric by senior officers so, consequently, 9650 billet-holders must often solicit OR work and then "sell" their results.

The source of these problems seems to be a rather deep-seated, historical one and was succinctly described by one

Lieutenant Colonel who wrote:

OR analysts are viewed with mixed emotions--the manipulation of analysis by Pentagon officials starting with McNamara 'Whiz Kids' who set out to prove the bottom line still persists in PA&E [Program Analysis and Evaluation]. [These officials] get their marching orders from the political appointees in the administration. Military analysts at that level are used by the services to conduct counter studies or to discredit work done by the administration if it is counter to service-perceived goals. We [Operations Analysts] are viewed as necessary evils and are tainted by the misuse of OR.

One suggested solution to this dilemma was to educate the officers filling supervisory positions over the analysts. In fact, it was felt by many respondents that common, basic OR education would lead not only to a greater degree of acceptance of the work of OR trained technicians but also to a more productive officer corps as a whole.

In regard to actual utilization of the billets, almost twenty percent of the respondents suggested that the productivity of OR billets might be improved by centralizing most of them in a single Operations Analysis Group. Being spread throughout the Marine Corps, as they are now, many analysts have found that the low incidence of OR work brought to them often does not justify their billets. This appeared to be particularly true at the Division/Wing level where the fast pace of daily activity brought about by what is perceived to be excessive demands often results in quick problem response at a superficial level of analysis. This is not conducive to the methodical and measured thought process often

required for thorough and accurate analytical work. Consequently, analysts at the lower command levels often either become embedded in administrative oblivion and structure politics or they are simply converted into efficiency experts assigned the task of acting as command hatchet-men, seeking out waste and misuse of resources.

Recommendations for correcting this deficiency were either to disestablish OR billets below the FMF level or, better, to centralize them within a single department. A central section, perhaps under the direction of a Deputy Chief of Staff for Operations Analysis, could accept viable projects submitted by other departments or commands throughout the Corps. Teams of one to six analysts (depending upon the size and scope of the problem) with appropriate backgrounds could be assigned to each project on an as-needed, as-available basis. This reorganization would, in the opinion of the respondents, lead to better long-range study planning and a less hectic daily press for results.

This recommendation goes counter to the findings of Thomas and DaCosta [Ref. 9]. In their survey of private industry they found that the most recent trend in the private sector has been away from centralized Operations Research departments. Their survey disclosed that "many respondents felt that by spreading Management Science [Operations Research] throughout the firm, practitioners would be better acquainted with the problems they had to solve and, therefore, would be more efficient" [Ref. 9, p. 103].

A number of individuals addressed the subject of OR work contracted out by the Marine Corps to civilian organizations. Many of the respondents expressed concern over the Marine Corps' apparent eagerness to issue contracts to outside sources who often charge exorbitant fees but who sometimes use incorrect OR techniques and/or produce questionable results. One individual, working in the area of Test and Evaluation, felt that "the Marine Corps is paying too much to 'Beltway Bandits' [civilian contractors] and their ilk for studies which are nothing more than mumbo jumbo". Many respondents felt that, if assigned to these tasks, they could do most of the technical work themselves thus producing better results at a fraction of the costs.

The general idea expressed was that, in order for Operations Analysts to be used most effectively, they should be "doers" rather than mere contract supervisors. If resource limitations prevent this, however (e.g., more work than can be done by available Marine analysts) then the analysts should at least be used to review the entire process of contracted studies and not just the finished product. Marine analysts should be included in the original contract negotiations with civilian agencies to ensure that the Marine Corps is not led into allowing meaningless or unnecessary tests to be performed. Operations Analysts should monitor the contracted work as it progresses and should, certainly, inspect the final results. According to the respondents, this monitoring and review work

must be a comprehensive quality control function. If the role filled by the 9650 is merely that of "riding herd" over previously contracted studies, then it was felt that an individual with a non-technical background such as a Systems Analyst (MOS 9652) could much more efficiently fill the billet.

The greatest number of comments received addressing any single subject (13) were those that recommended a reevaluation of the requirements for 9650 billets. While an annual review of all SEP billet requirements is conducted by HQMC, the respondents, generally, did not believe it to be comprehensive enough. Two main reasons were perceived by the respondents as being responsible for the unnecessary establishment of billets: (1) The billets were originally requested and approved by individuals who really didn't understand Operations Research and its applications and (2) the desire by some senior officials to add intelligent (but possibly unnecessary) officers to their staffs. One of the results of this billet inflation is that, very often, a promising, career-oriented officer is assigned to a billet that requires him to use very little of his special training and expertise. In fact, so much time appears to be spent by analysts working on special but non-analysis related staff projects that some individuals expressed doubt as to the need for any OR billets.

While there are, of course, billets that do require and utilize a working knowledge of OR techniques, it was rather obvious from the comments received that a truly comprehensive

review of all 9650 billet requirements would probably lead to the realization that some billets are either misused or not essential. Once identified, these billets could be dis-established or modified (e.g., replace a 9650 with a 9652) or the cause of misutilization could be corrected. The real problem, however, as viewed by those who have held the billets, would lie in the identification process. This would require a frank and honest review of the requirements for all 9650 billets and, while it was generally felt that the analyst holding an "unessential" billet would probably acknowledge such, there was little faith that his command would make the same acknowledgment. In fact, several individuals expressed concern that there might be retribution in the form of poor fitness reports if an organization lost any billets due to the honest evaluation of an incumbent. One respondent summarized the feelings expressed by several by writing,

What the Marine Corps needs is a truly covert, non-attributable billet validation procedure. No bureaucratic organization is going to give up a body voluntarily unless it can get something in trade of equal or greater benefit, i.e., the organization will always validate the billet. If I am scheduled to leave and my boss is told by HQMC (He starts calling. . . long before a person is actually scheduled to leave, demanding . . . replacement.) that they have decided not to fill this billet anymore, then his automatic inference is that I 'dropped the dime' and he gives appropriate award on my parting fitness report. Hence, what is needed is covert elicitation of billet validation from incumbents and protection in those cases where billets cannot be validated and will be eliminated (e.g., stall and stonewall on replacement).

If such a system of annual validation could be established, several individuals felt that as many as one-third of the

present number of 9650 billets might be made available for more productive use. (Indeed, it was seen above that almost 41% of the respondents stated that they spent 25% or less of their work time actually performing OR work.)

Two individuals did state that the Marine Corps needs more 9650 billets. They declared that there are many people (who are unaware of the value of applying OR techniques) attempting to solve problems which could be handled much more efficiently using analytical methods. Headquarters, Marine Corps apparently has a virtual gold mine of OR solvable problems just waiting to be recognized by someone versed in the field. What is needed, according to these individuals, is enough trained analysts to ferret these problems out and solve them.

Finally, two individuals recommended that prospective OR graduates be paired with their initial billet assignments as early as practical (at least two quarters prior to graduation and, ideally, a year prior). The current SEP monitor at HQMC realizes the importance to students of early billet notification and is attempting to do this now. Certainly, this does require planning and foresight on his part but unforeseen difficulties do arise and changes in prospective assignments must sometimes be made. Still, early notification does allow selection of elective courses oriented toward the billet to be filled and permits proper preparation on the part of the students. These students should bear in mind, however, that subsequent 9650 tours might be related to entirely different function areas than their initial billet assignments; hence,

they should not design elective programs restricted solely to one field but should try to maintain at least a minimum balance of OR subjects.

Some of the most interesting results of the survey were those obtained from the answers to question 12 as described in this chapter. Although usually no more than four or five of the 72 responding individuals addressed any one particular subject, many of the remarks appeared to be well thought-out and reflected the advantage of being based upon actual experience. It should be reemphasized, however, that, simply because one, two or even six individuals voiced an opinion, it does not necessarily mean that their comments are reflective of the entire population. Even with this caveat of subjectivity, however, it is possible to draw attention to the issues that have been raised and to make subsequent recommendations regarding them. This is done in the next chapter subsequent to a short comparison of the results of this study with those of studies done previously.

V. COMPARISONS, CONCLUSIONS AND RECOMMENDATIONS

A. COMPARISONS WITH PREVIOUS STUDIES

Since the format and conduct of this study did not exactly match those of investigations done previously, including Obert's survey of Army OR technique usage, the results cannot be collated in a parallel manner. However, some comparisons can be made.

Data analysis and statistical methods were the most frequently used OR techniques as in all the studies reviewed in Chapter I. Linear Programming was reported to be used by only about a third of the Marine Corps respondents, matching the results found in Obert's study of Army OR/SA engineers but falling quite a bit short of the apparent wide-spread usage reported by private firms (where LP-amenable problems such as resource allocation are possibly more numerous and better defined). Inventory Theory and the more advanced mathematical programming subjects were generally listed higher in frequency and importance orderings for corporate industry than they were in this study while Risk Analysis was found to be more widely used by Marine analysts than by private firms as reported by Thomas and DaCosta. Once again, this is probably a reflection of the natures of the two organizations. Private firms are more concerned with the resource allocation and sales problems while military operations characteristically require a high level of risk-taking.

Some of the most interesting and, perhaps because of the nature of employment of the persons surveyed, some of the most appropriate comparisons can be made between this study and the one conducted by Obert. The author found that a smaller percentage of Marines than Army officers: (1) Conducted original OR work, correlated OR work or reviewed OR work (74% to Obert's 87%). (2) Worked with established computer programs (66.7% to Obert's 80.3%). (3) Reported spending 50% or less of their work time doing OR work (66.7% to Obert's 73.2%). Also, unlike Obert's study, this investigation found that there is not a significant difference between the amount of work time spent by Captains/Majors and the amount of work time spent by Lieutenant Colonels/Colonels in the performance of OR-related tasks. Operations Research techniques which were found to be placed in nearly equal positions in orderings of frequency of use by Marine analysts and Army OR/SA engineers included Parametric Statistics, Probability Theory, Networks, Human Factors, Linear Algebra, Linear Programming, Non-Linear Programming and Dynamic Programming. Techniques which reflected a more widespread use by Army officers than by Marines included Combat Models and Decision and Risk Analysis, while the Marines reported greater usage of Experimental Design, Nonparametric Statistics, Cost Estimation, Calculus, Economics, Manpower Models and Input/Output Models. Barring these differences, however, the remainder of the results of this work were relatively similar to those of Obert's study.

B. CONCLUSIONS

This section includes the main conclusions drawn from the analysis of the data and comments obtained from the returned questionnaires.

1. Data Analysis

Of all the OR techniques listed in the questionnaire, the more advanced mathematical programming methods such as Nonlinear, Dynamic, Heuristic, Integer and Mixed Programming are used the least and believed to be the least important by the surveyed analysts in carrying out their daily duties as 9650's. Parametric Data Analysis, Probability Theory, Cost Effectiveness and Networks are the subjects used the most and believed to be the most important.

While it was found that there are differences in usage of individual techniques according to service rank groups (Captains and Majors use economic theory and related techniques such as Econometric Models, Cost Models and Forecasting as well as Linear Algebra and Computer Programming more often than do Lieutenant Colonels and Colonels while the latter use Risk Analysis, Gaming Models, Combat Models, Capital Budgeting and Policy Analysis more often than do the former), on an overall basis there is no statistical difference between the two groups based upon the breadth of usage of all of the OR techniques and application areas. What, then, might be possible causes for differences in overall breadth of usage?

It was found that there are statistically significant differences between breadths of usage of the techniques based

upon the general function areas related to the 9650 billets and based upon the type of OR work that the analysts were required to do the most. As might be expected, individuals working in a combination of functional areas and those performing original OR work were found to use a wider variety of OR techniques than those analysts employed in separate functional areas or those performing various other types or combinations of OR work.

Regarding perceived importance of the techniques and application areas listed in the questionnaire, individual differences also exist based upon the two service rank groups. Economic models (Econometric Models, Cost Estimation and Forecasting) as well as Equipment Replacement and Maintenance and Repair are perceived to be more important by Captains/Majors than by Lieutenant Colonels/Colonels while, on the other hand, most of the advanced mathematical programming methods (Non-linear, Dynamic, Integer and Mixed Programming) are perceived to be more important by the Lieutenant Colonels and Colonels.

Once again, however, no difference was found to exist between the two service rank groups based upon overall breadth of importance of all the techniques, nor was a difference found based upon the different types of OR work required to be performed by the individuals. (This might imply that the respondents placed a relative equality of importance on the techniques whether they used them or not.) The only possible causes for differences in overall breadth of perceived importance of the listed techniques was that attributed to variation in the general

function areas related to the 9650 billets. Those individuals working in the areas of Logistics and Operations and Plans assigned the lowest breadth of importance value to the techniques while those working in a combination of areas assigned the highest breadth of importance value.

Two other determinations were made regarding the usage and importance of techniques. First, there is a strong correlation between reported utilization of and perceived importance of the 35 OR techniques listed in the questionnaire (which is rather intuitive--the more a technique is used, the more likely it is that the user will find it to be important). Secondly, although most Marine analysts are not required to write their own computer programs, those who do write their own use Fortran as their most frequent programming language. (It was noted that most analysts do, however, interact with established or "canned" programs).

Analysis was also conducted to determine reasons for possible differences in the type of OR work required to be done by the 9650's, the percentage of work time Marine analysts spend doing OR work and the level of acceptance of OR work by those for whom the respondents worked. No differences in any of these three areas were found based upon the two service rank groupings (Captain/Major and Lieutenant Colonel/Colonel). However, the type of OR work performed was found to vary according to billet-related functional areas. (It is interesting to note that OR work is, at least, usually accepted by

most superiors and in no case was it found to be consistently not accepted.)

2. Comment Analysis

It is rather more difficult to draw hard and fast conclusions from the comment analysis section than from the data analysis section of this study. The subjective nature of the comments, as well as the fact that none of the topics discussed were mentioned by a majority of the respondents direct us to accept the fact that, rather than producing conclusions, the comments really simply raise issues that require further study.

The considerable response that was obtained when the analysts were asked to make recommendations for improving the utilization of 9650's appears to reflect at least some measure of job dissatisfaction on the part of the respondents. The main cause of this disappointment is probably the current misuse of some Marine Corps analysis resources. A strategy for alleviating this misuse can be developed by addressing the three major issues brought out by the comments. These are: (1) The need for education of 9650 billet supervisors. (2) The need for education of Marine Operations Analysts. (3) The need for reevaluation and possible reorganization of current 9650 billets.

a. Educating Supervisors

It is clear from the comments that there is some organizational resistance to the initiation and implementation

of OR work. This was judged to be due mainly to the misunderstanding on the part of some senior Marine officers as to what OR really is and what its value can be in the decision-making process. While it is understandable that a number of supervisors will be unversed in the more mundane esoterica of Operations Research, it should certainly be desirable to educate these officers so that the goal of proper utilization of analyst resources might be attained. Just as an infantry officer should be knowledgeable in the proper deployment and employment of his troops, so should a supervisor of Operations Analysts be capable of intelligently assigning and employing his personnel resources.

A more difficult problem to counter is that of engrained resistance to change and/or new ideas due to limited vision or funneled perception. Some individuals are simply opposed to innovative but obscure approaches to problems simply because their past experiences have included only simple, "head-on" approaches. While it may certainly be argued that in many cases the direct approach is the best course of action, supervisors should at least be open to suggestions concerning novel methods of reaching problem solutions.

b. Educating Operations Analysts

One factor contributing to 9650 job dissatisfaction is the frustration felt by the analyst when he is unexpectedly confronted by the realities of analytical work in the "real world". This is especially true in the cases of young analysts

who have recently finished their graduate work and are zealously approaching their first assignments confident that they are capable of performing creditable analytical work. What they are often surprised to find is that analysis in real life is not conducted in the same pristine and aseptic environment that they often enjoyed when approaching problems in the classroom. In fact, they may very quickly learn that their particular billet assignment requires them to do very little, if any, real analytical work or that they might spend several weeks on a project only to have the results ignored by decision-makers or, even worse, that they might see good analytical work disregarded for nontechnical reasons. The prospective 9650 should be made aware of the true nature of the environment that he is about to enter prior to his arrival at his initial assignment. He must understand that he may encounter institutional resistance to OR work and that, in the real world of give-and-take, compromises must sometimes be made for political reasons. Additionally, there will be times when the Operations Analyst must act as a technological change agent, soliciting problems that can be solved by OR techniques and then actively selling his results to the decision-makers. By educating the analyst in regard to occupational realities it might be possible to mitigate the frustrations he might feel because of unfulfilled expectations.

c. Reevaluation and Reorganization of Billets

There appear to be cases where Marine Operations Analysts are being improperly utilized. Disenchantment was

expressed by the 9650's because of low OR work incidence, limitations of available analytical resources (both personnel and computational hardware) and simple misunderstandings concerning the capabilities and limitations of analysis. They felt that spreading OR billets throughout the Marine Corps can, in some instances, lead to inefficiency and misuse of resources and that, at times, OR-related projects are unnecessarily contracted out by the Marine Corps to civilian agencies while the "in-house" analysts who could do the work themselves are assigned as Project Officers and relegated to a role of simple supervision and review. The opinion of many of the respondents was that 9650 billets are overdue for a hard, honest reevaluation of their technical skill requirements and organizational locations.

C. RECOMMENDATIONS

Based upon the conclusions drawn from the statistical analysis of the data and the issues raised by the comments submitted by the respondents, the author makes the following recommendations.

Because of the relatively large number of comments received addressing the apparent need for a thorough reevaluation of 9650 billet requirements, it is recommended that, during the next several required annual reviews of billet educational requisites, the Operations Research discipline sponsor (Deputy Chief of Staff for Research, Development and Studies) elicit candid comments from MOS 9650 billet incumbents regarding their perceptions of proper billet utilization. These comments should

then be incorporated into the normal billet review procedure to enhance the picture obtained by the discipline sponsor concerning the true requirements for the billets.

Additionally, and perhaps concurrently with the review of educational requirements, a detailed study should be conducted to determine if Marine Corps OR billets should be organized on a more centralized basis. Where the requirement for separately assigned OR sections or individuals cannot be justified, it might prove to be more efficient to group them into a single section, perhaps as an Operations Analysis Group under the control of the Deputy Chief of Staff for Research, Development and Studies. Under this organization, the conduct of studies might then be directed more effectively. In addition, an overall plan for reviewing original negotiations between the Marine Corps and civilian contractors, monitoring the progress of the contracted studies and inspection of the final results could be developed and employed by this group.

A course of instruction regarding the management of OR resources should be offered to and taken by all individuals (including 9650's) who are or will be responsible for supervising Marine Operations Analysts. This course could include such subjects as the Potential and Limitations of Operations Analysis, Management Techniques, Contract Management and Bureaucratic Realities. It could be taught at the Marine Corps Command and Staff College, should be at least one to two weeks long and could be taken by officers immediately prior to their arrival for duty in a supervisory position.

A short course in basic Operations Research could also be set up by the Marine Corps Extension School located at MCDEC, Quantico, Virginia. It should embrace, at a minimum, the very basics of OR to include foundational Probability Theory, simple Data Analysis and Statistical Inference, the theory behind Linear Programming, PERT and CPM, Design of Experiments and Technical Report Writing. This course could be made available to all Marines but should be specifically recommended to those officers who are filling 9650 billets but who do not possess the 9650 secondary MOS.

For those Marine officers attending the Naval Postgraduate School as a prerequisite to obtaining a 9650 secondary specialty, the course of instruction contained in Appendix E is submitted as a means of preparing themselves for the requirements that they will find subsequent to graduation. This program is certainly not all-inclusive nor does it take into consideration all of the driving and limiting factors that the administration of the Naval Postgraduate School must deal with when developing curricula. However, this program does contain most of the courses necessary to give the student at least a minimal knowledge in each of the areas found by this study to be commonly used and of importance. In addition, it is recommended that the Operations Research Department Chairman of the Naval Postgraduate School take into consideration either the establishment of a new course dealing specifically with such topics as Advocacy Analysis and Bureaucratic Realities of Analysis

or at least consider increasing the emphasis placed upon such subjects in existing NPS courses.

Finally, it is recommended that the Special Education Program monitor continue to place emphasis upon the early identification of 9650 billet vacancies and the pairing of these openings with prospective analysts while they are still attending school. These pairings should be accomplished (understanding that last minute changes may become necessary) at least six months to a year prior to the graduation of the students.

APPENDIX A

USMC OPERATIONS RESEARCH SURVEY

If you are currently serving in a MOS 9650 billet, please base your answers to all questions on present billet experiences. If you are not currently serving in a MOS 9650 billet but have done so in the past, please base your answers to all questions on experiences from your last 9650 billet assignment. If you have never served in a MOS 9650 billet, please state so now and do not answer any further questions. Otherwise, please continue.

1. a. What is the title of your 9650 billet? _____

- b. With what command is this billet located? _____

2. What is (was) your rank while serving in this 9650 billet? _____
3. Which of the following general function areas is this 9650 billet related to? (Circle one)
 - a. Manpower
 - b. Logistics
 - c. Finance
 - d. Operations and Plans
 - e. Test and Evaluation
 - f. Aviation
 - g. Instruction
 - h. Other: What area? _____

4. What type of Operations Research (OR) work does this 9650 billet require you to do the most? (Circle one)
 - a. Original OR work
 - b. Correlate the work of other researchers in your section
 - c. Review OR work done outside your section
 - d. Instructor
 - e. Other OR work
 - f. Do not do any OR work
5. Does this billet assignment require you to do your own computer programming?

 - a. If so, what computer language(s) do you use? _____

 - b. Why do you use this particular language? _____

6. Do you interact with any established computer programs (i.e., preprogrammed, "canned", manufacturer-provided software)? _____

7. How often do you use the following OR techniques and application areas?
(Place an X in the appropriate box)

	NEVER	SOMETIMES	ALWAYS
a. General OR Techniques			
1) <u>Linear Programming</u>			
2) <u>Nonlinear Programming</u>			
3) <u>Dynamic Programming</u>			
4) <u>Integer and Mixed Programming</u>			
5) <u>Heuristic Programming</u>			
6) <u>Bayesian Decision Analysis</u>			
7) <u>Networks, Flows and Graphs (PERT/CPM)</u>			
8) <u>Risk Analysis</u>			
9) <u>Cost Estimation</u>			
10) <u>Cost Effectiveness</u>			
11) <u>Reliability</u>			
12) <u>Inventory Theory</u>			
13) <u>Data Analysis and Statistical Inference (Parametric)</u>			
14) <u>Data Analysis and Statistical Inference (Nonparametric)</u>			
15) <u>Probability Theory</u>			
b. OR Modeling Techniques			
1) <u>Queueing Theory and Stochastic Models</u>			
2) <u>Gaming Models</u>			
3) <u>Combat Models</u>			
4) <u>Manpower Models</u>			
5) <u>Econometric Models</u>			
6) <u>Cost Models</u>			
7) <u>Input-Output Models</u>			
8) <u>Forecasting</u>			
c. Other Related Subjects			
1) <u>Calculus</u>			
2) <u>Linear Algebra</u>			
3) <u>Economics</u>			
4) <u>Capital Budgeting</u>			
5) <u>Policy Analysis</u>			
6) <u>Combat Analysis</u>			
7) <u>Equipment Replacement</u>			
8) <u>Maintenance and Repair</u>			
9) <u>Transportation</u>			
10) <u>Human Factors</u>			
11) <u>Design, Conduct and Evaluation of Experiments</u>			
12) <u>Computer Programming</u>			

8. What is the relative importance of having a working knowledge of these OR techniques and application areas in discharging the daily duties of your billet? (On a scale of 1='Extremely Important' to 5='Not Important At All'). Place an X in the appropriate box for each technique or subject.

	Extremely Important	1	2	3	4	5	Not Important
a. General OR Techniques							
1) <u>Linear Programming</u>							
2) <u>Nonlinear Programming</u>							
3) <u>Dynamic Programming</u>							
4) <u>Integer and Mixed Programming</u>							
5) <u>Heuristic Programming</u>							
6) <u>Bayesian Decision Analysis</u>							
7) <u>Networks, Flows and Graphs (PERT/CPM)</u>							
8) <u>Risk Analysis</u>							
9) <u>Cost Estimation</u>							
10) <u>Cost Effectiveness</u>							
11) <u>Reliability</u>							
12) <u>Inventory Theory</u>							
13) <u>Data Analysis and Statistical Inference (Parametric)</u>							
14) <u>Data Analysis and Statistical Inference (Nonparametric)</u>							
15) <u>Probability Theory</u>							
b. OR Modeling Techniques							
1) <u>Queueing Theory and Stochastic Models</u>							
2) <u>Gaming Models</u>							
3) <u>Combat Models</u>							
4) <u>Manpower Models</u>							
5) <u>Econometric Models</u>							
6) <u>Cost Models</u>							
7) <u>Input-Output Models</u>							
8) <u>Forecasting</u>							
c. Other Related Subjects							
1) <u>Calculus</u>							
2) <u>Linear Algebra</u>							
3) <u>Economics</u>							
4) <u>Capital Budgeting</u>							
5) <u>Policy Analysis</u>							
6) <u>Combat Analysis</u>							
7) <u>Equipment Replacement</u>							
8) <u>Maintenance and Repair</u>							
9) <u>Transportation</u>							
10) <u>Human Factors</u>							
11) <u>Design, Conduct and Evaluation of Experiments</u>							
12) <u>Computer Programming</u>							

9. Other than those listed above, what OR techniques and/or application areas do you feel you should have a working knowledge of in order to efficiently do your job? (Please list the top five in order of importance.)

10. a. Approximately what percentage of your work time is actually spent doing OR work in comparison to your other duties? (Circle one)

1) 0%	4) 75%
2) 25%	5) 100%
3) 50%	

- b. If your answer to question 10.a. was 1) or 2), in what area is most of your work time spent? _____

11. Generally, what is the acceptance level of those whom you work for towards OR work? (Circle one)

a. OR work is accepted without question
b. OR work is usually accepted
c. OR work is rarely accepted
d. OR work is never accepted

12. In your opinion, how could OR billets be better utilized? (Please use the reverse side if more space for response is required.)

13. Do you wish to receive a copy of the results of this survey? _____

APPENDIX B

OR TECHNIQUE USAGE AND IMPORTANCE FREQUENCIES

USAGE	Raw Score			Percentage		
	NEVER	SOMETIMES	ALWAYS	NEVER	SOMETIMES	ALWAYS
TECHNIQUE						
a. GENERAL OR TECHNIQUES						
1) Linear Programming	43	23	0	65	35	0
2) Nonlinear Programming	56	10	0	85	15	0
3) Dynamic Programming	57	8	1	86	12	2
4) Integer and Mixed Programming	61	5	0	92	8	0
5) Heuristic Programming	59	6	1	89	9	2
6) Bayesian Decision Analysis	48	18	0	73	27	0
7) Networks Flows and Graphs	14	49	3	21	74	5
8) Risk Analysis	37	26	3	56	40	5
9) Cost Estimation	18	43	5	27	65	8
10) Cost Effectiveness	13	43	10	20	65	15
11) Reliability	25	33	8	38	50	12
12) Inventory Theory	52	12	2	79	18	3
13) Data Analysis and Statistical Inference (Parametric)	13	38	15	20	58	23
14) Data Analysis and Statistical Inference (Nonparametric)	22	31	13	33	47	20
15) Probability	15	37	14	23	56	21
b. OR MODELING TECHNIQUES						
1) Queueing Theory & Stoch. Models	40	25	1	61	38	2
2) Gaming Models	41	22	3	62	33	5
3) Combat Models	37	25	4	56	38	6
4) Manpower Models	38	22	6	58	33	9
5) Econometric Models	48	15	3	73	23	5
6) Cost Models	31	31	4	47	47	6
7) Input-Output Models	42	23	1	64	35	2
8) Forecasting	42	21	3	64	32	5
c. OTHER RELATED SUBJECTS						
1) Calculus	32	30	4	48	45	6
2) Linear Algebra	40	23	3	61	35	5
3) Economics	33	26	7	50	40	11
4) Capital Budgeting	49	14	3	74	21	5
5) Policy Analysis	45	15	6	68	23	9
6) Combat Analysis	34	26	6	52	40	9
7) Equipment Replacement	32	31	3	48	47	5
8) Maintenance and Repair	32	30	4	48	45	6
9) Transportation	38	28	0	58	42	0
10) Human Factors	31	29	6	47	44	9
11) Design, Cond. & Eval. of Exps.	20	35	11	30	53	17
12) Computer Programming	28	26	12	42	40	18

IMPORTANCE

TECHNIQUE	Extremely Important					Very Important					Average Importance					Little Importance					Not Important				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
a. GENERAL OR TECHNIQUES																									
1) Linear Programming	4	7	18	13	24	6	11	27	20	36															
2) Nonlinear Programming	0	4	10	18	34	0	6	15	27	52															
3) Dynamic Programming	0	1	9	24	32	0	2	14	36	48															
4) Integer & Mixed Programming	0	1	11	15	39	0	2	17	23	59															
5) Heuristic Programming	2	1	8	13	42	3	2	12	20	64															
6) Bayes. Dec. Analy.	1	7	14	14	30	2	11	21	21	45															
7) Networks, Flows and Graphs	5	22	21	11	7	8	33	32	17	11															
8) Risk Analysis	5	15	16	11	19	8	23	24	17	29															
9) Cost Estimation	12	13	17	12	12	18	20	26	18	18															
10) Cost Effectiveness	15	16	18	10	7	23	24	27	15	11															
11) Reliability	10	17	17	12	10	15	26	26	18	15															
12) Inventory Theory	2	7	10	22	25	3	11	15	33	38															
13) Data Analysis and Stat. Inf. (Param.)	22	17	12	7	8	33	26	18	11	12															
14) Data Analy. & Stat. Inf. (Nonparametric)	21	15	9	11	10	32	23	14	17	15															
15) Probability Theory	22	19	9	6	10	33	29	14	9	15															
b. OR MODELING TECHNIQUES																									
1) Queueing Theory & Stochastic Models	2	12	15	18	19	3	18	23	27	29															
2) Gaming Models	5	16	9	15	21	8	24	14	23	32															
3) Combat Models	9	12	6	12	27	14	18	9	18	41															
4) Manpower Models	12	5	13	18	18	18	8	20	27	27															
5) Econometric Models	2	11	12	19	22	3	17	18	29	33															
6) Cost Models	8	19	13	14	12	12	29	20	21	18															
7) I-O Models	5	11	7	16	27	8	17	11	24	41															
8) Forecasting	7	13	11	12	23	11	20	17	18	35															
c. OTHER RELATED SUBJECTS																									
1) Calculus	8	17	13	11	17	12	11	20	17	26															
2) Linear Algebra	4	10	24	9	19	6	15	36	14	29															
3) Economics	11	15	13	14	13	17	23	20	21	20															
4) Capital Budgeting	2	9	14	15	26	3	14	21	23	40															
5) Policy Analysis	6	11	14	16	19	9	17	21	24	29															
6) Combat Analysis	9	11	13	8	25	14	17	20	12	38															
7) Equipment Repl.	2	16	11	16	21	3	24	17	24	32															
8) Maintenance & Repair	4	12	15	16	19	6	18	23	24	29															
9) Transportation	1	13	11	21	20	2	20	17	32	30															
10) Human Factors	11	13	13	11	18	17	20	20	17	27															
11) Design, Cond. & Eval. of Exps.	23	13	6	11	13	35	20	9	17	20															
12) Computer Progr.	18	16	12	9	11	27	24	18	14	17															

APPENDIX C

USAGE FREQUENCIES BY SERVICE RANK. FREQUENCY--CAPT/MAJ = 52

TECHNIQUE	Raw Score			Percentage		
	NEVER	SOMETIMES	ALWAYS	NEVER	SOMETIMES	ALWAYS
a. GENERAL OR TECHNIQUES						
1) Linear Programming	34	18	0	65	35	0
2) Nonlinear Programming	45	7	0	87	13	0
3) Dynamic Programming	46	5	1	88	10	2
4) Integ. & Mixed Programming	49	3	0	94	6	0
5) Heuristic Programming	46	5	1	88	10	2
6) Bayesian Decision Analysis	38	14	0	73	27	0
7) Networks, Flows and Graphs	10	41	1	19	79	2
8) Risk Analysis	31	20	1	60	38	2
9) Cost Estimation	14	34	4	27	65	8
10) Cost Effectiveness	12	33	7	23	63	13
11) Reliability	19	26	7	37	50	13
12) Inventory Theory	41	10	1	79	19	2
13) Data Analy. & Statistical Inference (Parametric)	11	28	13	21	54	25
14) Data Analy. & Statistical Inference (Nonparametric)	19	22	11	37	42	21
15) Probability Theory	13	26	13	25	50	25
b. OR MODELING TECHNIQUES						
1) Queueing Theory & Stoch. Models	32	19	1	62	37	2
2) Gaming Models	34	16	2	65	31	4
3) Combat Models	31	18	3	60	35	6
4) Manpower Models	30	17	5	58	33	10
5) Econometric Models	36	13	3	69	25	6
6) Cost Models	23	25	4	44	48	8
7) I-O Models	34	18	0	65	35	0
8) Forecasting	30	19	3	58	37	6
c. OTHER RELATED SUBJECTS						
1) Calculus	25	23	4	48	44	8
2) Linear Algebra	30	19	3	58	37	6
3) Economics	23	25	4	44	48	8
4) Capital Budgeting	42	9	1	81	17	2
5) Policy Analysis	38	12	2	73	23	4
6) Combat Analysis	28	20	4	54	38	8
7) Equipment Replacement	25	24	3	48	46	6
8) Maintenance and Repair	25	23	4	48	44	8
9) Transportation	29	23	0	56	44	0
10) Human Factors	25	22	5	48	42	10
11) Design, Cond. & Eval. of Exps.	16	27	9	31	52	17
12) Computer Programming	19	22	11	37	42	21

Frequency--LT. Col./Col. = 14

TECHNIQUE	Raw Score			Percentage		
	NEVER	SOMETIMES	ALWAYS	NEVER	SOMETIMES	ALWAYS
a. GENERAL OR TECHNIQUES						
1) Linear Programming	9	5	0	64	36	0
2) Nonlinear Programming	11	3	0	79	21	0
3) Dynamic Programming	11	3	0	79	21	0
4) Integ. & Mixed Programming	12	2	0	86	14	0
5) Heuristic Programming	13	1	0	93	7	0
6) Bayesian Decision Analysis	10	4	0	71	29	0
7) Networks, Flows and Graphs	4	8	2	29	57	14
8) Risk Analysis	6	6	2	43	43	14
9) Cost Estimation	4	9	1	29	64	7
10) Cost Effectiveness	1	10	3	7	71	21
11) Reliability	6	7	1	43	50	7
12) Inventory Theory	11	2	1	79	14	7
13) Data Analy. & Statistical Inference (Parametric)	2	10	2	14	71	14
14) Data Analy. & Statistical Inference (Nonparametric)	3	9	2	21	64	14
15) Probability Theory	2	11	1	14	79	7
b. OR MODELING TECHNIQUES						
1) Queueing Theory & Stoch. Models	8	6	0	57	43	0
2) Gaming Models	7	6	1	50	43	7
3) Combat Models	6	7	1	43	50	7
4) Manpower Models	8	5	1	57	36	7
5) Econometric Models	12	2	0	86	14	0
6) Cost Models	8	6	0	57	43	0
7) I-O Models	8	5	1	57	36	7
8) Forecasting	12	2	0	86	14	0
c. OTHER RELATED SUBJECTS						
1) Calculus	7	7	0	50	50	0
2) Linear Algebra	10	4	0	71	29	0
3) Economics	10	1	3	71	7	21
4) Capital Budgeting	7	5	2	50	36	14
5) Policy Analysis	7	3	4	50	21	29
6) Combat Analysis	6	6	2	43	43	14
7) Equipment Replacement	7	7	0	50	50	0
8) Maintenance and Repair	7	7	0	50	50	0
9) Transportation	9	5	0	64	36	0
10) Human Factors	6	7	1	43	50	7
11) Design, Conduct & Eval. of Exps.	4	8	2	29	57	14
12) Computer Programming	9	4	1	64	29	7

APPENDIX D

IMPORTANCE FREQUENCIES BY SERVICE RANK. Importance--Capt/Maj = 52

TECHNIQUE	Raw Score					Percentage				
	Extremely Important				Not Important	Extremely Important				Not Important
	1	2	3	4	5	1	2	3	4	5
a. GENERAL OR TECHNIQUES										
1) Linear Programming	2	5	15	10	20	4	10	29	19	38
2) Nonlinear Program.	0	3	6	14	29	0	6	12	27	56
3) Dynamic Programming	0	1	5	19	27	0	2	10	37	52
4) Integ. & Mixed Prog.	0	1	7	11	33	0	2	13	21	63
5) Heuristic Programming	2	1	5	9	35	4	2	10	17	67
6) Bayesian Dec. Analy.	0	6	11	9	26	0	12	21	17	50
7) Networks, Flows and Graphs	4	19	16	8	5	8	37	31	15	10
8) Risk Analysis	4	12	13	9	14	8	23	25	17	27
9) Cost Estimation	11	11	13	8	9	21	21	25	15	17
10) Cost Effectiveness	13	12	13	8	6	25	23	25	15	12
11) Reliability	9	12	15	7	9	17	23	29	13	17
12) Inventory Theory	1	7	8	16	20	2	13	15	31	38
13) Data Analy. & Stat. Inference (Param.)	19	14	8	5	6	37	27	15	10	12
14) Data Analy. & Stat. Inference (Nonparam.)	17	12	6	9	8	33	23	12	17	15
15) Probability Theory	20	14	5	4	9	38	27	10	8	17
b. OR MODELING TECHNIQUES										
1) Queueing Theory & Stochastic Models	1	10	12	13	16	2	19	23	25	31
2) Gaming Models	3	14	7	9	19	6	27	13	17	37
3) Combat Models	7	11	3	7	24	13	21	6	13	46
4) Manpower Models	10	5	9	12	16	19	10	17	23	31
5) Econometric Models	2	10	10	12	18	4	19	19	23	35
6) Cost Models	7	15	10	9	11	13	29	19	17	21
7) I-O Models	5	8	6	9	24	10	15	12	17	46
8) Forecasting	6	12	8	8	18	12	23	15	15	35
c. OTHER RELATED SUBJECTS										
1) Calculus	7	13	9	9	14	13	25	17	17	27
2) Linear Algebra	4	7	19	6	16	8	13	37	12	31
3) Economics	8	14	10	10	10	15	27	19	19	19
4) Capital Budgeting	0	9	11	12	20	0	17	21	23	38
5) Policy Analysis	2	11	12	13	14	4	21	23	25	27
6) Combat Analysis	6	9	11	4	22	12	17	21	8	42
7) Equipment Repl.	2	14	8	12	16	4	27	15	23	31
8) Maintenance & Repair	4	11	12	10	15	8	21	23	19	29
9) Transportation	1	11	9	17	14	2	21	17	33	27
10) Human Factors	9	10	11	8	14	17	19	21	15	27
11) Des., Cond. & Eval. Exp.	18	11	5	7	11	35	21	10	13	21
12) Computer Programming	16	12	8	7	9	31	23	15	13	17

Importance--LT Col/Col = 14

Raw Score

Percentage

TECHNIQUE	Extremely Important					Not Important	Extremely Important				Not Important
	1	2	3	4	5	1	2	3	4	5	
a. GENERAL OR TECHNIQUES											
1) Linear Programming	2	2	3	3	4	14	14	21	21	29	
2) Nonlinear Programming	0	1	4	4	5	0	7	29	29	36	
3) Dynamic Programming	0	0	4	5	5	0	0	29	36	36	
4) Integ. & Mixed Prog.	0	0	4	4	6	0	0	29	29	43	
5) Heuristic Programming	0	0	3	4	7	0	0	21	29	50	
6) Bayesian Dec. Analy.	1	1	3	5	4	7	7	21	36	29	
7) Networks, Flows and Graphs	1	3	5	3	2	7	21	36	21	14	
8) Risk Analysis	1	3	3	2	5	7	21	21	14	36	
9) Cost Estimation	1	2	4	4	3	7	14	29	29	21	
10) Cost Effectiveness	2	4	5	2	1	14	29	36	14	7	
11) Reliability	1	5	2	5	1	7	36	14	36	7	
12) Inventory Theory	1	0	2	6	5	7	9	14	43	36	
13) Data Analy. & Stat. Inf. (Parametric)	3	3	4	2	2	21	21	29	14	14	
14) Data Analy. & Stat. Inf. (Nonparametric)	4	3	3	2	2	29	21	21	14	14	
15) Probability Theory	2	5	4	2	1	14	36	29	14	7	
b. OR MODELING TECHNIQUES											
1) Queueing Theory & Stochastic Models	1	2	3	5	3	7	14	21	36	21	
2) Gaming Models	2	2	2	6	2	14	14	14	43	14	
3) Combat Models	2	1	3	5	3	14	7	21	36	21	
4) Manpower Models	2	0	4	6	2	14	0	29	43	14	
5) Econometric Models	0	1	2	7	4	0	7	14	50	29	
6) Cost Models	1	4	3	5	1	7	29	21	36	7	
7) I-O Models	0	3	1	7	3	0	21	7	50	21	
8) Forecasting	1	1	3	4	5	7	7	21	29	36	
c. OTHER RELATED SUBJECTS											
1) Calculus	1	4	4	2	3	7	29	29	14	21	
2) Linear Algebra	0	3	5	3	3	0	21	36	21	21	
3) Economics	3	1	3	4	3	21	7	21	29	21	
4) Capital Budgeting	2	0	3	3	6	14	0	21	21	43	
5) Policy Analysis	4	0	2	3	5	29	0	14	21	36	
6) Combat Analysis	3	2	2	4	3	21	14	14	29	21	
7) Equipment Repl.	0	2	3	4	5	0	14	21	29	36	
8) Maintenance & Repair	0	1	3	6	4	0	7	21	43	29	
9) Transportation	0	2	2	4	6	0	14	14	29	43	
10) Human Factors	2	3	2	3	4	14	21	14	21	29	
11) Des., Cond. & Eval. Exp.	5	2	1	4	2	36	14	7	29	14	
12) Computer Programming	2	4	4	2	2	14	29	29	14	14	

APPENDIX E

EXAMPLE OF AN OPERATIONS ANALYSIS CURRICULUM FOR U.S.M.C. STUDENTS ATTENDING THE NAVAL POSTGRADUATE SCHOOL

First Quarter

Introductory Computing for Operations Analysis
Topics in Calculus
Probability
History & Nature of Operations Analysis
Linear Algebra
Seminar for OA students

Second Quarter

Linear Programming
Selected Topics from Advanced Calculus
Probability and Statistics
Introduction to Mathematical Economics
Seminar for OA students

Third Quarter

Statistics
Stochastic Models I
Computational Methods for OR
Networks, Flows and Graphs
Seminar for OA students

Fourth Quarter

Utility Theory & Resource Allocation
Human Factors in System Design I
Analysis of Operational Data
Systems Simulation
Seminar for OA students

Fifth Quarter (includes 6 week Experience Tour)

Systems Analysis I
Combat Models & Wargaming
Seminar for OA students

Sixth Quarter

Non-Linear and Dynamic Programming
Stochastic Models II
Design of Experiments

Elective
Seminar for OA students

Seventh Quarter

Thesis Research
Reliability and Weapon System Effectiveness
Evaluation of Human Factors Data
Elective
Seminar for OA students

Eighth Quarter

Thesis Research
Cost Estimation
Elective
Elective
Seminar for OA students

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